

Editorial

This year we focus on invertebrate biology and conservation. Invertebrates have been greatly neglected in research and in conservation generally and in the western Indian Ocean. This neglect led to the 'Invertebrate Scoping Workshop' in Washington in 2001 to try and develop a mechanism for integrating invertebrates into the work of the World Conservation Union (IUCN). The relevance of this to the region is discussed in the first of the invertebrate papers in this issue of *Phelsuma*. This highlights several important points: the conservation issues that face invertebrates, monitoring possibilities and Red Listing. These are followed up in other papers and notes concerning population declines, monitoring and the dynamics of invasive species. Overviews of specific taxonomic groups are included with the compilation of all data on the relatively conspicuous Seychelles hawkmoths and the faunistic records of the familiar but overlooked shield-bugs.

The systematic bias against invertebrates is indicated by the following comparison. Invertebrates make up over 98% of the biodiversity of the Seychelles islands but the species based conservation projects carried out to date have involved 20 animal species, only 4 (20%) of which were invertebrates. Similarly monitoring programmes have covered at least 77 animal species, of which 21 (28%) were invertebrates. The neglect of invertebrates may partly reflect differences in conservation status. However, where Red Listing of a whole taxonomic group has been initiated, high threat levels are found in invertebrates. For example, in this issue it is reported that of the species where sufficient data exists for Red Listing, 72% of endemic molluscs are threatened, as are 64% of endemic moths and butterflies. This compares to 54% of endemic birds and 47% of endemic reptiles. From this brief comparison it is apparent that a high proportion of the endemic fauna of the Seychelles islands is threatened. It can be argued that some of the endemic vertebrates would be extinct or on the edge of extinction had intensive conservation work not been focussed on them; in the absence of any comparable attention for the invertebrates we are probably losing many species to extinction. It is to be hoped that the actions and initiatives described here will enable us to correct this imbalance and to preserve a more representative proportion of the region's biodiversity. This is essential if truly sustainable, functional ecosystems are to be preserved.

This issue of *Phelsuma* focuses primarily on the Seychelles islands, this reflects the invertebrate work in the region, whilst there is some invertebrate research in the Mascarenes and enormous research efforts have been underway in Madagascar in recent years, active conservation lags far behind.

J. Gerlach
Editor

APOLOGY

This issue of *Phelsuma* is being distributed considerably later than expected. This is due to problems with the sponsorship covering the publication of the journal. As a result we have had to return to earlier, cheaper procurement methods and have been considerably delayed. We hope to be able to secure new sponsorship for next year's issue.

Chairman's Report

On 26th December last year, we started our day with a cup of coffee in bed and the radio switched on to catch the early morning news. This was a usual start to what turned out to be a most unusual day. The news was dramatic; an undersea earthquake off Sumatra and a huge tidal wave sweeping across Sumatra, Thailand and the Andaman Islands. Slowly, as the morning progressed the news of the tidal wave or tsunami (to give it the name we all use now) became ever more depressing, India and Sri Lanka had been ravaged, buildings gone, fishermen lost, tourists swept away - all so difficult to comprehend.

At 9.00 a.m. we had a call from worried family in England (05.00 GMT) which added to our concern. Half an hour later, a call to the meteorological office on Mahé solicited a casual reply about no imminent danger because of the distance between Seychelles and Sumatra. Shortly thereafter we heard that the Maldives were underwater and we began to discuss taking a bag of supplies up the hill "just in case". But what could we do for all the tortoises and terrapins? Nothing was more important than they.

Our deliberations were interrupted by a call from one of our volunteers (Crispin Brume) who was then on Mahé. He told us that Victoria had been flooded right up to the Clock Tower, at Beau Vallon the sea was behaving strangely but appeared to pose no danger. We rushed down to the beach and witnessed the amazing sight of the tide rising to the top of the beach-crest and then suddenly ebbing to well beyond its usual low tide level. This was easier to appreciate in the confined space of the Silhouette harbour (Fig. 1) where we timed the surge at two minutes from high tide to low tide - a cycle of four minutes from high tide to high tide. This continued throughout the afternoon until at dusk we could no longer see it. Warnings about a higher tide at 8.00 p.m. turned out to be no problem. No noticeable damage to the marine ecosystem was apparent over the next few days.



Fig. 1. Water flowing off the reef-flat in the Silhouette harbour, 26th December 2004

While there was a fair amount of damage in those areas of Mahé and Praslin with shallow bays and restrictions such as the harbours and reclaimed land around Victoria, loss of life was reported as two or possibly three persons. The most visible long-term damage was on Curieuse Island where a large section of the causeway was washed away and despite protection from the mangroves, a fair portion of the boardwalk was destroyed.

None of the outer islands reported serious problems probably because they mostly lie in relatively deep water. They all experienced the tidal surge but even that was not noticed on Aldabra and Assumption. Historical records show that this same tidal surge occurred previously in 1883 when Krakatoa erupted.

Aside from this horrific day in the lives of people around the Indian Ocean and the unimaginable loss of life, this financial year was relatively calm for Nature Protection Trust of Seychelles. Life on Silhouette changed in January when the existing 12 room hotel closed and preparations got underway for the building of a new 116 room hotel. A hotel of this size will undoubtedly bring big changes to the island with a dramatic increase in the size of the population. NPTS will play an important role in the environmental and landscape management of the hotel site during the construction stage.

Our major sponsors this year are listed below and we are extremely grateful for their support:

Peter Kistler of SAN	Donation for equipment
Rick Watson	Donation
ExoTerra (Rolf C. Hagen Inc.)	Terrapin food
U.S. Ambassador's Self-Help Fund	Project funding
Conservation International	Project funding
Islands Development Company	Logistical and other support
Pool & Patel	Honorary Auditors

Volunteers

Once again, Guy van Heygen held the fort for us on two occasions when we were away from Silhouette. He also delivered the terrapin food from ExoTerra.

In June, Nick Ball spent 10 days on Silhouette and reported a new sheath-tailed bat roost near Gratte Fesse (*Phelsuma* 12) but subsequent visits to the cave have not confirmed this.

Crispin Brume spent two weeks in December continuing the turtle monitoring at Grande Barbe. He filled in for Global Vision International GVI to whom we are very grateful for running an excellent programme of volunteer support that enabled us to monitor the entire hawksbill turtle season at Grande Barbe. This resulted in 84 confirmed hawksbill nests (and a further 112 possible nests) on Silhouette this year.

Our last volunteer this year was Dr. Christina Oliver, a botanist from Edinburgh Botanic Gardens, who spent some very quiet evenings observing pollinators of the Endangered plant *Impatiens gordonii*.

Scientific Visitors

Dr. Massimo Pandolfi and Alessandro Tanferma visited Silhouette in December to assist us with trapping Seychelles kestrels to extract blood samples. This was in support of a genetic research project by Dr. Jim Groombridge.

A group of freshwater biologists accompanied by staff from the Ministry of Environment carried out a survey in November, during our absence from Silhouette, but no results of the survey have been made available to us.

Dr. Michael Samways spent two weeks on Silhouette in January, assisting with dragonfly habitat assessments.

The annual Sussex University field course was once again led by Drs. M. Frogley and D. Kniveton. This year one group visited and carried out group research exercises and assisted us with voluntary work.

The International School again spent time on Silhouette as part of their biology course. They also helped with weeding our invasive plants in our Forest Rehabilitation Project site.

Overseas Visits and Meetings

In November we attended the 3rd IUCN World Conservation Congress in Bangkok, Thailand. This huge gathering of so many people and organisations involved in conservation proved to be very stimulating and, as always, an excellent venue for making valuable contacts. Having attended the previous IUCN congresses, we found the workshops somewhat repetitive with very little new ground covered. We displayed a poster at the venue for the Species Survival Commission meetings.

In July Justin presented a paper on giant tortoise taxonomy at the 5th International Symposium on Tropical Biology in Bonn. In January he attended the International Conference on Biodiversity: Science and Governance at UNESCO in Paris and presented a poster on the Indian Ocean Biodiversity Assessment.

Seychelles Giant Tortoise Conservation Project

The breeding success reported last year was repeated this year with a doubling of the number of hatchlings. This is definitely our “flagship” project and is the major attraction for visitors to Silhouette. The increased number of cruise ship visitors has meant that for the first time we have had more people wishing to adopt tortoises than the number of tortoises available - however, a loaded incubator will soon address this.

Steady growth has resulted in 47 hatchlings passing the 400 grams weight threshold for graduation to the large “hatchling house” enclosure. Of the first and largest group, the *Dipsoschelys arnoldi* “O.J.” was the fastest growing and heaviest hatchling until the steady weight increase of *D. hololissa* “David” closed the gap. All five *D. hololissa* hatchlings have been very slow to develop during their first year but appear to develop faster thereafter.

With the continued success of the breeding programme we are now able to plan the reintroduction phase. Our regular long-term supporters, the British Chelonia Group, have made the reintroduction of tortoises to Silhouette one of the projects for support by their 2005 Conservation Appeal. The Nederlandse Schildpadden Vereniging will be supporting habitat restoration at Mare aux Cochons in preparation for tortoise reintroduction there.

Seychelles Terrapin Conservation Project

This year we have been able to make some improvements to the terrapin ponds with the help of the builders who are here for the hotel project. We have had four large ponds built for the *Pelusios castanoides* and four of eight smaller, shallower ponds for the *P. subniger*. The last four ponds have been held up because the masons’ expertise is needed elsewhere. Some of the materials for the ponds were donated by Mr. S. Khan of Civil Construction Co. Ltd.

We had only partial breeding success this year with one *P. castanoides* hatching on 1st January 2005. It has been suggested by the Durrell Wildlife Preservation Trust that our problems may have to do with keeping the incubator too warm. We have used the same incubation temperature very successfully for *P. subniger* eggs, but will try lower temperatures next season.

Silhouette Conservation Project

With funding from the U.S. Ambassador’s Self-Help Fund for some equipment, a signboard (asking people to help protect the plants) and the production of a trail guide, we opened a short lowland trail this year. The trail is intended to give day visitors and less energetic visitors a chance to enjoy a forest walk in the short time available to them. The trail goes through an area of forest rehabilitation which will highlight the work we do on Silhouette. It will also demonstrate the benefit to the environment of the removal of invasive alien species.

We have spent much more time this year monitoring the sheath-tailed bat roost, especially in the light of the increased activity occasioned by the hotel project. Thus far no negative signs have been detected and the population remains around the mid-thirties. Exploration of the surrounding area has found two other “caves” that have bat guano in them but have not been in use for some time. The best of these roosts had its entrance obscured by a dense clump of coconut scrub that has now been cleared away in the hope that the roost will once again be occupied.

A major aspect of the sheath-tailed bat monitoring has been our wish to install an infra-red camera in the main roost, connected to a monitor in the information centre/laboratory. We hope to secure funding for this equipment in June/July. This will enable us to monitor the bats on a permanent basis without disturbance and will clarify many questions regarding their behaviour and reproductive biology.

This has been another year of success for all NPTS projects carried out by dedicated staff and volunteers and funded by visitors' donations and private sponsors. I am grateful for the unstinting support of my wife Gill (Honorary Secretary of NPTS), to Jules Larue who does all the big physical work and has developed into a top-class guide, and also to Justin who carries the burden of all the scientific work and the worries of producing this journal.

Ron Gerlach
Chairman

2004 Publications

[Ami = Amirantes; Ald = Aldabra; Sey = Seychelles]

- ATTIE, M, BOURGOIN, T, FOUILLAUD, M, REYNAUD, B & BONFILS, J Distribution and ecology of *Mahellus determinatus* (Distant, 1917) (Hemiptera: Cicadomorpha : Cicadellidae) *Afr. Entomol.* **12**; 63-70 [Sey]
- AUMEERUDDY, R & PAYET, R Management of the Seychelles sea cucumber fishery: status and prospects. *FAO Fisheries Technical Paper* **463**; 239-246. [Sey]
- AUSTIN, JJ, ARNOLD, EN & JONES, CG Reconstructing an island radiation using ancient and recent DNA: the extinct and living day geckos (*Phelsuma*) of the Mascarene islands. *Mol. Phyl. Evol.* **31**; 109-122. [Ald, Sey]
- BENJAMIN, SP Taxonomic revision and phylogenetic hypothesis for the jumping spider subfamily Ballinae (Araneae, Salticidae). *Zool. J. Lin. Soc.* **142**; 1-82. [Sey]
- BOGGEMANN, M & WESTHEIDE, W Interstitial Syllidae (Annelida: Polychaeta) from Mahe (Seychelles). *J. Nat. Hist.* **38**; 403-446. [Sey]
- BURGESS, N, D'AMICO HALES, J, UNDERWOOD, E & DINERSTEIN, E *Terrestrial Ecoregions of Africa and Madagascar, A Conservation Assessment*. Island Press [Ald, Sey]
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- DUCOUSSO, M, BENA, G, BOURGEOIS, C, BUYCK, B, EYSSARTIER, G, VINCELETTE, M, RABEVOHITRA, R, RANDRIHASIPARA, L, DREYFUS, B & PRIN, Y The last common ancestor of Sarcolaenaceae and Asian dipterocarp trees was ectomycorrhizal before the India-Madagascar separation, about 88 million years ago. *Mol. Ecol.* **13**; 231-236. [Sey]
- FEARE, CJ & DOHERTY, PF Jr Survival estimates of adult Sooty Terns *Sterna fuscata* from Bird Island, Seychelles. *Ibis* **146**; 475-480. [Sey]
- FISHELSON, L & DELAREA, Y Taste buds on the lips and mouth of some blennioid and gobioid fishes: comparative distribution and morphology. *J. Fish Biol.* **65**; 651-665. [Sey]
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- RENNER, SS & ZHANG, L-B Biogeography of the *Pistia* clade (Araceae): Based on chloroplast and mitochondrial DNA sequences and Bayesian divergence time inference. *Syst. Biol.* **53**; 422-432. [Sey]
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Developing strategies for invertebrate conservation: the case for the Seychelles islands

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Abstract: Approaches to invertebrate conservation in Seychelles are reviewed. These comprise taxonomic research and Red List assessments, monitoring of populations and the status of habitats, monitoring of introduced species and research into their ecology and research into the status of pollinators. Further research is required on the effects of invasive species, identification of key pollinators and the effects of climate change. Red List assessments are given for threatened Mollusca, Orthopteroidea and Lepidoptera.

Keywords: invertebrate conservation, invasive species, pollinators, Red List assessments, taxonomy

In 2001, a meeting was held in Washington to investigate the practicalities of developing a global strategy for invertebrate conservation. This ‘Invertebrate Scoping Workshop’ proposed 8 main actions needed for the full integration of invertebrates in the planning and conservation assessments of the World Conservation Union (IUCN) (IUCN/SSC/CBSG 2001). To date, these have only been partially implemented due at least in part to a lack of funding. The recommendations are being implemented at a local level in Seychelles and this provides an indication of the relevance of these actions to developing conservation action.

Taxonomic Specialist Groups of IUCN’s Species Survival Commission cover only a small proportion of the world’s invertebrates. This has led to a recent increase in the number of regional groups. The Seychelles islands fall within the remit of the Southern African Invertebrate Specialist Group. As the workshop’s recommendations were aimed at global conservation, not all aspects are relevant to a single country.

The following is a summary of the workshop recommended outputs to address the priority issues in invertebrate conservation

1. Lack of taxonomic and conservation related knowledge
 - 1.1 Develop linkage and collaboration with the wider invertebrate community
 - 1.2 Co-ordinate taxonomic and conservation activity at individual and agency level
 - 1.2.1 Specialist Group chairs and members need to contact editors of

journals that publish taxonomic descriptions and encourage them to include a Red List assessment as part of descriptions/revisions/checklists.

- 1.3 Generate and link reliable and accessible web-based biodiversity and status data
 - 1.3.1 Ensure sufficient linkage to existing key (including, if possible georeferenced specimen based) databases. This needs to be part of the functionality of SIS or coordinated through the Global Biodiversity Information Facility (GBIF).
- 1.4 Influence and support relevant efforts (e.g. Global Taxonomic Initiative and GBIF) to encourage increasing current resource levels
- 1.5 Facilitate identification of priority taxa of conservation concern.
 - 1.5.1 The Invertebrate Conservation Committee needs to coordinate efforts to target key taxa for assessing invertebrate conservation status across ecosystems.
 - 1.5.2 Specialist Groups should be encouraged to produce user-friendly specimen identification guides.
- 1.6 SSC/IUCN needs to address the fact that species protection laws can prevent specimen collecting for scientific and conservation purposes. The ability to undertake such work is essential for obtaining reliable data on the species status.

2. Habitat destruction

- 2.1 Accurate assessment of invertebrate biodiversity loss relating to type and intensity of existing habitat destruction.
 - 2.1.1 Promote the implementation of accurate loss assessments
- 2.2 Proactive baseline assessments for monitoring of invertebrates as related to trends and future potential habitat destruction.
 - 2.2.1 Promote the use of invertebrates in geographical prioritisation exercise
 - 2.2.2 Development and promotion of standardised international sampling methodologies
 - 2.2.3 Review the impact on invertebrate communities in priority habitats (e.g. caves, mangroves)
- 2.3 Assessing synergistic impacts of habitat destruction with other threatening processes as agents of local and/or global extinction
 - 2.3.1 To highlight instances where the interplay of different impacts has resulted in exceptionally high loss of invertebrate diversity such that a discontinuity has occurred.

3. Human resource issues

- 3.1 Enhance the current information and networking mechanism so as fully to utilise the knowledge and ability of the international invertebrate community.

4. Invasive species
 - 4.1 To raise the consciousness of the problem
 - 4.2 Enhance the representation within SSC of invertebrate issues in management of invasive species
 - 4.3 Facilitate better information exchange about invasive invertebrate species and their effects on other species
5. Lack of awareness
 - 5.1 To harness information on the value of invertebrates in maintaining ecological integrity and health and to disseminate the information in popular form through print and electronic media.
6. Pollinator loss
 - 6.1 Quantify and characterise the problem.
7. Climate change
 - 7.1 Monitor fluxes in selected taxa across all ecosystems. Document and publicise these results.
8. Exploitation and sustainable use
 - 8.1 Identify those species that are threatened through exploitation
 - 8.1.1 Compile red data list of those species that are , or may be, unsustainable exploited
 - 8.2 Review the inappropriate use of CITES higher taxon listing where it relates to “trade” (movement) in scientific specimens and facilitating trade where it has a conservation benefit.
 - 8.3 Review the conservation value, economic viability and enforcement implications attached to popular invertebrate farming activities.

Actions carried out in Seychelles in relation to these outputs are:

1. Taxonomy and Red Listing

Through the work of the Indian Ocean Biodiversity Assessment 2000-2005 (IOBA) of the Nature Protection Trust of Seychelles (NPTS) a world-wide network of taxonomists has been developed primarily to ensure the identification of all material from Seychelles (action 1.1). The outputs of the IOBA comprise individual taxonomic revisions, the publication of monographs and the development of a biodiversity database. Database linkage is being developed by the Africa Environment Information Network (action 1.3.1). The monographic series on the Seychelles fauna, scheduled for launch in 2005 is aimed at providing user-friendly specimen identification guides (action 1.5.2).

Red List assessments are being provided by the monographic series (with some assessments published separately). The recent establishment of a Red List focal point in the Seychelles Ministry of Environment provides a coordinated approach

to the development of a national Red List and the assessments from the IOBA will be contributed to the national listing process. The Red List assessments available to date comprise the Lepidoptera, Orthopteroidea and Molluscs (Appendix I).

As of 2005, the editorial policy of *Phelsuma* is that all future taxonomic and inventory papers concerning species not assessed for the Red List should include Red List assessment as far as practical (action 1.2.1).

The distribution and population assessments provided by the IOBA will allow prioritisation of taxa of conservation concern (action 1.5.1).

Research agenda: Continuation of ongoing taxonomic revisions.

Action requirements: Continuation of ongoing taxonomic revisions and Red Listing.

2. Habitat destruction

The IOBA provides baseline data for the status of most invertebrate species, trends in status can be detected for a small number of taxa and these are being evaluated as part of the Red Listing process (action 2.1.1). The methods used by the IOBA are standard and appropriate for use by diverse professional and amateur researchers, as such this represents the development of standardised monitoring protocols (action 2.2.2). In addition monitoring methods have been developed for the giant tenebrionid beetle *Pulposipus herculeanus* (Gerlach 2005a), snails and diurnal hawkmoths (Appendix II).

To date, no reviews have been carried out on the status of invertebrates in the priority habitats, (action 2.2.3). In Seychelles, these represent freshwater marshes, mangroves and high forest. Priority conservation sites in the granitic islands have been identified by the IOBA in terms of animal diversity, plant diversity and the distribution of threatened species (GERLACH 2003a). This is being further refined by the development of a Seychelles biodiversity atlas.

Research agenda: Monitoring of priority taxa and habitats.

Action requirements: Evaluation of the status of invertebrates in priority habitats using the biodiversity data collected by the IOBA.

3. Human resource issues

Although there is a considerable volume of invertebrate knowledge in Seychelles, there remains a problem of insufficient use of appropriate human resources in the country. Accordingly, action 3.1 remains inadequately addressed. Currently a significant proportion of conservation projects employ overseas staff for invertebrate work and fail to support existing Seychelles expertise.

Action requirements: Existing capacity in Seychelles for invertebrate research and conservation should be more effectively deployed. This is a matter of capacity utilisation and not capacity building.

4. Invasive species

There is a high degree of awareness of the importance of invasive species in Seychelles (action 4.1) with the issue being highlighted in all status reviews and

workshops and the formulation of an Invasive Alien Species National Committee. The issue has mainly been highlighted with reference to habitat change and the impacts of introduced mammals on bird populations. The publication of the first invasive species list will be a first step in improving information exchange about all invasive species (action 4.3). Only limited research has been carried out on the impacts of invasive invertebrate species (e.g. the carnivorous snail *Euglandina rosea* (SAY, 1840) and the crazy ant *Anoplolepis gracilipes* (SMITH, 1857) – HAINES & HAINES 1979, GERLACH 1999, 2001, 2004, 2005b). More work is also required on the impact of invasive alien plants on the endemic invertebrate fauna.

Research agenda:

Distribution - the distribution of notable invasive species of all taxa needs to be monitored, and specific research carried out into their impacts.

Ecology– although almost all literature considers invasive species to be a problem for conservation, there are situations where introduced species become established as keystone species. In Seychelles, such a case has been identified with the cockroaches *Pycnoscelus indicus* (FABRICIUS) and *P. surinamensis* LINNAEUS. These form a major part of the invertebrate biomass on the sea-bird islands of Aride, Cousin and Cousine and are the main components of the diet of the Endangered Seychelles magpie robin *Copsychus seychellarum* Newton, 1867 (SAMWAYS 2000; LE MAITRE 2002). Removal of these introduced species, even if feasible, would have major negative impacts on the magpie robin. Similar dependence on invasive species has been identified in the Seychelles bee hawkmoth *Cephonodes tamsi* GRIVEAUD, 1960 which is currently dependent on the invasive weed *Lantana camara* as its main nectar source (GERLACH 2000).

Research should concentrate on invasive predators and parasites, and plants, that are likely to have significant impacts on habitats, and which can be realistically controlled or locally eradicated.

Action requirements: where practical invasive species should be controlled before becoming problematic. This could be achieved for the snail *Euglandina rosea* through manual collection. Generally the preservation of diverse, dynamic habitats should minimise problems of invasion. Removal of invasive plants has been highly successful on the small and contained island of Cousine and in small areas of Silhouette, increasing the area of occupancy for various indigenous and endemic reptiles and birds, as well as for invertebrates.

5. Lack of awareness

Invertebrate conservation remains a low priority generally and their value in ecology has not been widely publicised. Further work in this area is required. Nevertheless, through major fora such as the Expanding the Ark Coalition and the IUCN Species Survival Commission's Invertebrate Conservation Committee, some progress is being made.

6. Pollinator loss

This is an emerging issue in global conservation. It has not yet been addressed in

Seychelles and little research has been carried out on this topic to date, it is a major priority for the future (action 6.1).

Research agenda: Research into the identity and status of pollinators is urgently required to determine which indigenous species are the most significant pollinators and how these interact with introduced pollinators, and which plant specific pollinators are essential for the pollination of the keystone and threatened endemic plants. Only a small amount of research has so far addressed this topic (FLOATER 1995; CADBURY 2001). Other related issues that require further research are the significance and identity of seed and seedling predators and seed distributors.

Action requirements: At present the key actions required are implementation of the research agenda. Until such time as reliable data on this issue are available, a precautionary approach should be adopted and all habitats managed to maximise natural systems.

7. Climate change

No monitoring or research relating to the impact of climate change on invertebrates has been carried out in Seychelles.

Research agenda: Monitoring should be continued or initiated using taxa selected as potential indicators of the impacts of climate change. Suitable taxa include Mollusca (monitoring ongoing – see section 2). The Seychelles giant millipede (*Sechelleptus seychellarum* (DESJARDINS, 1834)) also appears to be a good candidate as it is highly sensitive to changes in rainfall (GERLACH *et al.* 2005).

Action requirements: Implementation of the research agenda.

8. Exploitation and sustainable use

No terrestrial invertebrates are exploited in Seychelles at present. Exploited marine species include molluscs, corals, spanner crab, lobsters and sea-cucumbers. Red List assessments of marine invertebrates is required and should prioritise these exploited taxa (action 8.1.1). Similarly invertebrate farming (action 8.3) is restricted to the tiger prawns on Coetivy and the pearl farming on Praslin; the conservation implications and regulation of these need ongoing monitoring.

Research agenda: Monitoring of exploited species.

Action requirements: Maintenance of ongoing monitoring of harvest levels. Red List assessments of marine invertebrates is required, with assessment of exploited taxa being a priority.

In addition to the general aspects summarised above species-specific actions have been carried out for the larger invertebrates present on Fregate island (FERGUSON & PEARCE-KELLY 2005; GERLACH 2005A; GERLACH *et al.* 2005), specifically the Fregate island giant tenebrionid beetle *Pulposipus herculeanus* SOLIER, 1848, Seychelles giant scorpion *Chiromachus ochropus* KOCH, 1838, giant millipede *Sechelleptus seychellarum* and Fregate island snail *Pachnodus fregatensis* VAN MOL & COPPIS, 1980. These involve captive breeding, ecological research, habitat management, control of potential predators and investigation of the status of pathogens (specifically entomopathogenic fungi).

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Appendix I. Red List status of Lepidoptera, Orthopteroidea and Mollusca

The Seychelles islands have a highly diverse and phylogenetically significant endemic invertebrate fauna. The fauna of islands is widely reported to be particularly threatened in the current biodiversity crisis. Despite this there is little information

on the status of island faunas, with the exception of vertebrates. A small number of Seychelles invertebrate species have been included on the IUCN Red Lists; the 1996 (BAILLE & GROOMBRIDGE 1996) list included the Seychelles crow butterfly *Euploea mitra* (Endangered), the butterfly *Phalanta philiberti* (Endangered), the swallowtail butterfly *Papilio phorbata nana* (Extinct), Seychelles fineliner damselfly *Teinobasis a. alluaudi* (Endangered), Seychelles giant tenebrionid beetle *Pulposipus herculeanus* (Critically Endangered) and the giant clams *Tridacna maxima* and *T. sqamosa* (conservation dependent). In 1997 the first attempt at a comprehensive listing was made with the publication of a Red Data Book for the islands (GERLACH 1997). This used the 1994 Red List Criteria and the limited distribution data available at the time, 195 invertebrate species were listed and of these two molluscs were added to the global Red List (HILTON-TAYLOR 2000).

The Indian Ocean Biodiversity Assessment 2000-2005 provides the first full survey of the biodiversity of the Seychelles islands. The completion of the surveys of the granitic islands in 2003 (GERLACH 2003a) allows the status of the fauna to be comprehensively assessed. Here we report on the results of the first invertebrate groups to be assessed using the new data: Mollusca, Lepidoptera and Dictyoptera.

Data for Seychelles invertebrates comprises distributions for all species but only limited data on population trends for a small number of taxa; accordingly most assessments rely on range restrictions. In the assessments tabulated below criteria D1 applies to small populations, D2 to restricted range (under 20km²), B1abv and 2abv to restricted range with declining populations and B1biii and 2biii to restricted range with declining habitat (e.g. marsh associated species). Categories are abbreviated as follows: DD = data deficient; LC = Least Concern; VU = Vulnerable; EN = Endangered; CR = Critically Endangered.

Mollusca include a high proportion of threatened species (27%). Almost all of these are categorised as Vulnerable on the basis of restricted ranges (83%). The main additional threats are historical habitat destruction leading to population extinction (12%). 17% of Orthopteroidea are threatened, all these threatened species are Vulnerable due to restricted range. Overall 28% of Lepidoptera are threatened, with notably high levels in the Tineidae (42%), Gracillariidae (50%), Oecophoridae (30%), Momphidae (32%), Metachandidae (32%), Arctiidae (31%), Sphingidae (31%) and Nymphalidae (18%). Of these the majority are threatened by association with a threatened habitat or restricted ranges. Excluding habitat association and range restriction, high threat levels are found only in the Sphingidae (31%) and Nymphalidae (28%). It is notable that these are the largest Lepidoptera in the islands, mostly species laying eggs in a clumped pattern. These species may be vulnerable to egg or larval parasitoids and predators. In the Nymphalidae two species appear to have declined dramatically in the mid 1900s (*Euploea mitra* remaining abundant until 1959 but declining subsequently and *Phalanta philiberti* declining between 1909 and 1953, when it was last recorded). No change in probable predators (bird species) is known to have occurred in this time period but several insect parasitoids were introduced in biological control programmes. It is suspected that such introductions may have contributed to the decline in these species.

Table 1. Threatened Orthopteroidea of Seychelles. Globally threatened species in bold type

Status	Islands ¹	Extent of occurrence(km ²)	Area of occupancy(km ²)	Records ²			Restricted association	Seychelles Red List
				1892	1905-10	1975-2005		
ORTHOPTERA								
<i>Catantops a. axillaris</i>	1	6	6.0		+		coastal	Vu (D2)
GRYLLIDAE								
<i>Gryllantherus tomentosus</i>	1	5.0	5.0		+	+	>500m coastal	Vu (D2)
<i>Malgasia</i> sp.	1	25000	12.5		+	+	>300m	Vu (B2)
<i>Seychellestia nitidula</i>	1	10.0	10.0		+	+		Vu (D2)
MOGOPLISTIDAE								
<i>Archinocephalus mevedevi</i>	1	11.7	11.7			+	coastal	Vu (D2)
<i>Ectatoderus aldabrae</i>	1	11.7	11.7			+	coastal	Vu (D2)
<i>Ornebius stenus</i>	1	11.7	11.7			+	coastal	Vu (D2)
MYRMECOPHILIDAE								
<i>Myrmecophilus microscopicus</i>	1	2.7	2.7			+	lowland	Vu (D2)
<i>Myrmecophilus seychellensis</i>	3	300	4.0			+	lowland	Vu (D2)
TETRIGIDAE								
<i>? Comoros</i>						+		Vu (D2)
<i>Endemic</i>	1	5.0	5.0		+	+	>400m	Vu (D2)
<i>Endemic</i>	1	5.0	5.0		+	+	>400m	Vu (D2)
BLATTELLIDAE								
<i>Endemic</i>	1	5.0	5.0		3	-	high marsh	Vu (D2)
<i>Endemic</i>	1	5.0	5.0		16	-	high marsh	Vu (B2)
<i>Endemic</i>	1	5.0	5.0		16	-	high marsh	Vu (B2)
<i>Endemic</i>	1	5.0	5.0		16	-	coastal	Vu (B2)
<i>Endemic</i>	1	5.0	5.0		16	-	lowland	Vu (B2)
NOCTUIDAE								
<i>Endemic</i>	2	800	10.0		-	+	open grass	Vu (D2)
PHYLPHAGIDAE								
<i>Endemic</i>	1	5.0	5.0		1	-	high forest	Vu (D2)
ANISOLABIDAE								
<i>Endemic</i>	1	5	5.0		+	+	high forest	Vu (B2)
<i>Endemic</i>	1	5	5.0		-	+	high forest	Vu (B2)
SPONGIPHORIDAE								
<i>Endemic</i>	1	15	15.0		+	+	high forest	Vu (D2)
<i>Endemic</i>	2	300	15.0		+	+	palm bases	Vu (B2)

1. Islands – number of islands occupied. 2 – numbers of individuals in collections or present but not quantified or only observed (+)

Table 2. Threatened Lepidoptera of Seychelles (columns as Table 1), globally threatened species in bold type.

Status	Islands	Extent of occurrence (km ²)	Area of occupancy (km ²)	Recorded	Restricted association	Seychelles Red List
			1892-1910	1956-60	1968-2005	
TINEIDAE	<i>Afrocelastis lochaea</i>	300	22.10	?	?	EN (B2abiii)
	<i>Amphixystis crobylora</i>	10	10	-	-	VU (D2)
	<i>Amphixystis cyathodesma</i>	10	10	-	-	CR (B1abv,2abv)
	<i>Amphixystis ensifera</i>	300	122	-	-	EN (B1abv,2abv)
	<i>Amphixystis fricata</i>	300	122	-	-	EN (B1abv,2abv)
	<i>Amphixystis ichnora</i>	300	122	-	-	EN (B1abv,2abv)
	<i>Amphixystis laciniata</i>	152.5	152.5	14	14	EN (B1abv,2abv)
	<i>Amphixystis nephalia</i>	300	172	-	-	EN (B1abv,2abv)
	<i>Amphixystis psittacella</i>	300	172	-	-	EN (B1abv,2abv)
	<i>Amphixystis psittacella</i>	300	172	-	-	EN (B1abv,2abv)
	<i>Amphixystis rorida</i>	300	172	-	-	EN (B1abv,2abv)
	<i>Amphixystis roseostriata</i>	300	172	-	-	EN (B1abv,2abv)
	<i>Cryptophodex concolorata</i>	46	46	-	-	VU (D2)
	<i>Erechthias calypsa</i>	10	10	1	1	VU (D2)
	<i>Erechthias methodica</i>	10	10	1	1	VU (D2)
	<i>Erechthias molynda</i>	175	201	29	29	EN (B1abv,2abv)
	<i>Erechthias polyplaga</i>	46	46	-	-	EN (B1abv,2abv)
	<i>Erechthias trichodora</i>	152.5	152.5	12	12	EN (B1abv,2abv)
	<i>Opogona fovea</i>	300	20	6	6	EN (B1abv,2abv)
	<i>Opogona heliogramma</i>	0.01	0.01	9	9	EN (B1abv,2abv)
	<i>Opogona sacchari</i>	1625	172.3	-	-	EN (B1abv,2abv)
	<i>Linea copinata</i>	300	172.3	28	28	EN (B1abv,2abv)
	<i>Linea copinata</i>	10	10	1	1	VU (D2)
GRACILLARIIDAE	<i>Acroecrops angelica</i>	600	47.5	1	1	EN (B1abv,2abv)
	<i>Caloptilia transtilla</i>	46	46	2	2	VU (D2)
	<i>Capnodes luxuriosa</i>	300	172.3	2	2	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	10	10	1	1	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
	<i>Capnodes triaria</i>	152.6	152.6	15	15	EN (B1abv,2abv)
OECOPHORIDAE	<i>Anachastis digitata</i>	10	10	1	1	VU (D2)
	<i>Bignaniella bignaniella</i>	46	46	1	1	VU (D2)
	<i>Bignaniella simpsonella</i>	46	46	1	1	VU (D2)
	<i>Bignaniella tourefortiacoella</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
	<i>Capnodes simplex</i>	46	46	1	1	VU (D2)
BLASTOPHAGIDAE	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
	<i>Paracleda tricapitata</i>	152.5	152.5	17	17	EN (B1abv,2abv)
BLASTOPHAGIDAE	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
	<i>Blasobasis integrata</i>	0.3	0.3	-	-	VU (D2)
GELECHIDAE	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
	<i>Apocritica chromatica</i>	152.5	152.5	11	11	EN (B1abv,2abv)
MONIPHIDAE	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)
	<i>Chlorocampa effera</i>	20	20	2	2	VU (D2)

<i>Ascalenia isotacta</i>	2	300	172.5	1	16	2	marsh	EN (B2abiii)
<i>Cosmopterix flavofasciata</i>	4	80000	152.5	6	7	-	coastal	EN (B1abv, 2abv)
<i>Cosmopterix mimetis</i>	1	4.6	152.5	3	7	-	high forest	EN (B1abv, 2abv)
<i>Gynandacta superharpalea</i>	2	900	152.5	3	10	-	coastal	VU (D2)
<i>Stigmaphorhiza acris</i>	2	300	152.5	3	10	-	-	EN (B1abv, 2abv)
<i>Stigmaphorhiza hergelypta</i>								EN (B1abv, 2abv)
METACHANDIIDAE								
<i>Metachanda coetivella</i>	1	1.5	1.5	3	7	-	coastal	VU (D2)
<i>Metachanda columinata</i>	2	300	172.5	8	10	-	high forest	VU (D2)
<i>Metachanda cryptiricha</i>	1	20	20	1	-	-	high marsh	EN (B1abv, 2abv)
<i>Metachanda gidicata</i>	1	152.5	152.5	1	11	-	marsh	EN (B1abv, 2abv)
<i>Metachanda inatavaga</i>	1	152.5	152.5	1	11	-	coast	EN (B1abv, 2abv)
<i>Metachanda piniginella</i>								EN (B1abv, 2abv)
EPERMENIIDAE								
<i>Epermenia cf. moza</i>	1	20	20	1	-	-	VU plant	VU (D2)
LYONEUTIDAE								
<i>Lyoneuta probolactis</i>	2	300	172.5	22	1	-	-	EN (B1abv, 2abv)
HELBOLDIIDAE								
<i>Epigrosca sp.</i>	5	240	3.2	-	-	5	<i>Pisonia</i> forest	VU (D2)
EPARCHIDAE								
<i>Achyra massalis</i>	9	800	168.3	26	25	-	coastal	EN (B1abv, 2abv)
<i>Ancylosis niveicostella</i>	1	4.6	172.5	2	9	-	coastal	VU (D2)
<i>Cadarena pudorata</i>	2	152.5	172.5	2	9	-	lowland	EN (B1abv, 2abv)
<i>Chapiniprocis trapezalis</i>	4	152.5	172.5	3	10	-	lowland	EN (B1abv, 2abv)
<i>Prochiloptera parvianata</i>	2	200	172.5	1	1	-	coastal	EN (B1abv, 2abv)
<i>Glaucochelis musccla</i>	2	300	172.5	22	10	-	coastal	EN (B1abv, 2abv)
<i>Noorda blitealis</i>	4	152.5	172.5	3	10	-	coastal	EN (B1abv, 2abv)
<i>Eurhyarodes tricoloralis</i>	4	300	201.5	33	16	-	lowland	EN (B1abv, 2abv)
<i>Heritiatodes derogata</i>	2	1.54	153.8	1	1	-	VU plant	VU (D2)
<i>Herpetogramma licarsisalis</i>	1	0.01	0.01	1	27	-	lowland	EN (B1abv, 2abv)
<i>Herpetogramma phaeopisialis</i>	3	162.5	200	13	13	-	coastal	EN (B1abv, 2abv)
<i>Lamprosema chloresalis</i>	2	152.5	172.5	1	13	-	lowland	EN (B1abv, 2abv)
LAMPROSEMAIDAE								
<i>Lamprosema delhommealis</i>	1	300	172.5	5	33	-	coastal	EN (B1abv, 2abv)
<i>Almidea abactis</i>	2	1.5	172.5	1	1	-	-	EN (B1abv, 2abv)
<i>Plectocera basalis</i>	1	4.6	172.5	1	1	-	coastal	VU (D2)
<i>Leptocera sabinausalis</i>	1	1.5	172.5	1	1	-	coastal	EN (B1abv, 2abv)
<i>Pycnodura irregularis</i>	3	300	172.5	3	14	-	coastal	EN (B1abv, 2abv)
<i>Pyrausta manihotalis</i>	3	15000	172.5	3	14	-	coastal	EN (B1abv, 2abv)
<i>Pyrausta manihotalis</i>	3	80000	172.5	3	29	-	lowland	EN (B1abv, 2abv)
CHOREUTIDAE								
<i>Stenographes verticea</i>	1	4.6	172.5	1	1	-	coastal	VU (D2)
<i>Anthophila gratiosa</i>	1	4.6	172.5	1	1	-	coastal	VU (D2)
FORICRIDAE								
<i>Foricrion curvella</i>	1	4.6	172.5	1	1	-	coastal	VU (D2)
Cryptophlebia caeca								
<i>Cryptophlebia conchopleura</i>	1	4.6	172.5	1	1	-	coastal	VU (D2)
<i>Ophiocryptes logranis</i>	1	4.6	172.5	1	1	-	high forest	EN (B1abv, 2abv)
ARCHIDAE								
<i>Archia asirpica</i>	3	304	174.5	12	32	1	lowland	EN (B1abv, 2abv)
<i>Archia asirpica</i>	1	50	174.5	1	1	-	high forest	VU (D2)
<i>Malana senecella</i>	1	2.2	2.2	8	1	-	coastal	VU (D2)
<i>Uelheisa latrix</i>	1	2.2	2.2	8	1	-	coastal	VU (D2)
<i>Uelheisa pulchella</i>	1	2.2	2.2	8	1	-	coastal	VU (D2)
NOCTUIDAE								
<i>Acontia zelleri</i>	1	11.7	11.7	3	3	-	coastal	VU (D2)
<i>Acontia longidentifera microtica</i>	1	11.7	11.7	3	3	-	coastal	VU (D2)

<i>Bocana</i> sp.	1	1625	172.5	13	1	VU (D2)
<i>Gesonia bansalis</i>	4	1625	172.5	13	1	EN (B1abv, 2abv)
<i>Porphyrythia cf. ragusanoides</i>	1	152.5	182.3	7	-	VU (D2)
<i>Progonia patronalis</i>	3	900	182.3	33	-	EN (B1abv, 2abv)
<i>Rhiesata moestialis</i>	1	4.6	4.6	2	-	EN (B1abv, 2abv)
<i>Spodoptera ciliatum</i>	1	4.6	4.6	2	-	EN (B1abv, 2abv)
NOLIDAE						
<i>Celania tarzaniae</i>	1	4.6	4.6	2	-	VU (D2)
<i>Magega nysusseta</i>	1	4.6	4.6	2	-	EN (B1abv, 2abv)
SPHINGIDAE						
<i>Macronomodes tamsi</i>	3	1625	200	1	-	CR (G1)
<i>Macronomastum alluaudi</i>	3	300	172.5	1	-	Extinct
<i>Nephroleptis</i>	3	330	172.5	1	-	VU (B1abii, 2abiii)
<i>Leptogastera timorensis</i>	3	330	172.5	1	-	VU (B1abii, 2abiii)
HESPERIIDAE						
<i>Relapidas n. mathias</i>	1	6.6	6.6	-	+	VU (D2)
XYPHOPHILIDAE						
<i>Euploea mitra</i>	2	300	172.5	57	+	EN (B1abv, 2abv)
<i>Phipponia madagascariensis</i>	2	1625	6.6	4	-	VU (D2)
<i>Phalantia philiberti</i>	2	1625	6.6	25	-	Extinct

Table 3. Threatened Mollusca of Seychelles. Current data, with historical data in parentheses. Population and area trends since 1994. Globally threatened species in bold type.

MOLLUSCA	Islands occupied	Population estimate	Population decline	Range total	Habitat	Seychelles Red List
Neritidae						
<i>Neritina gagates</i>	1	600	-	0.12	freshwater	Vu (D1, 2)
<i>Neritina pulligera knorri</i>	1	600	-	0.12	freshwater	Vu (D1, 2)
<i>Neritina pulligera stumfi</i>	2	500	-	0.10	freshwater	Vu (D1, 2)
<i>Neritina consimilis</i>	2	600	-	0.12	freshwater	Vu (D1, 2)
<i>Septaria borbonica</i>	2	600	-	0.12	freshwater	Vu (D1, 2)
Paludomus ajanensis ¹	2	100	20%	<0.01	freshwater	En (D)
<i>Paludina thalassii</i>	2	5,000	-	0.01	freshwater	Vu (D2)
<i>Trombidaria ligata</i>	2	5,000	-	0.01	coastal axils	Vu (D2)
<i>Trombidaria (ligatella) ligata</i>	2	5,000	-	0.01	coastal axils	Vu (D2)
<i>Semipelta parvur</i>	2	18,500	-	18.47	forest	Vu (D2)
<i>Caeciloides mauritiana</i>	2	3,400	-	3.74	lowland	Vu (D2)
<i>Allopeus gracile</i>	8	354,400	-	7.00	palm forest	Vu (D2)
<i>Edentulina dussumieri praslinus</i>	1	1,700	-	1.00	palm forest	Vu (D2)
<i>Edentulina dussumieri reserveae</i>	1	1,700	-	1.00	palm forest	Vu (D2)
<i>Edentulina moreleti</i>	2	84,000	-	3.50	<i>Dracaena</i> axils	Vu (D2)
*Gulella 'silhouetteae'	1	<216,000	-	2.16	moss forest	Vu (D2)
*Gulella 'thomassetti'	1	<1,000	-	0.01	high forest	CR (B2ab(iii))
<i>Stereotele nevilli parvidentata</i>	1	525,800	-	18.59	high forest	Vu (D2)
<i>Imperturbatia violascens</i>	1	23,500	-	6.00	high forest	Vu (D2)
<i>Silhouetteia silhouetteae</i>	1	1,773,400	-	17.67	high forest	Vu (D2)
<i>Careoradula perelegans</i>	2	29,100	-	19.03	high forest	Vu (D2)
<i>Conturbatia crenata</i> ³	1	0?	>80%	0.35	low forest	CR (A2a)
<i>Pridiscus spinatus</i>	1	64,700	-	2.16	high forest	Vu (D2)

Acavidae	<i>Priodonta costatus</i>	5	8,000	-	8.00	-	high forest	Vu (D2)
	<i>Stylodonta unidentata sebertiae</i>	1	1,000	-	10.84	-	marshes	Vu (D1, 2)
	<i>Stylodonta unidentata globosa</i>	1	6,960,700	-	8.59	-	forest	Vu (D2)
	<i>Stylodonta unidentata praslina</i>	1 (2)	700	-	7.50	-	forest	Vu (D1, 2)
'Chronidae'	<i>Stylodonta unidentata parva</i>	1	50,000	-	5.00	-	palm forest	Vu (D2)
	<i>Stylodonta studeriana</i>	1 (3)	12,100	-	12.12	-	forest	Vu (D2)
	<i>Nesokaliella subpurpuritula</i>	2 (3)	8,000	-	8.00	-	high forest	Vu (D2)
	<i>Nesokaliella minuta</i>	1	500,000	-	5.00	-	high forest	Vu (D2)
Eugonulidae	<i>Nesokaliella intermedia</i>	1	44,300	-	3.28	-	high forest	Vu (D2)
	<i>Lousia duponti</i>	1	?	-	8.00	-	lowland	Vu (D2)
	<i>Pipipnita lewisoniae</i>	1	1,700	-	7.16	-	high forest	Vu (D2)
	<i>Pillula malhestana</i>	2	3,200	-	7.16	-	high forest	Vu (D2)
Cerastidae	<i>Pachnodus (P.) velutinus</i>	1	5,000	-	5.00	-	moss forest	Extinct
	<i>Pachnodus (P.) niger niger</i>	1	3,000	-	5.00	-	high forest	Vu (D2)
	<i>Pachnodus (P.) niger subfuscus</i>	1	3,000	-	5.00	-	palm forest	Vu (D2)
	<i>Pachnodus (P.) niger x velutinus</i>	1	3,525,000	-	16.00	-	forest	Vu (D2)
	<i>Pachnodus (P.) lionetti</i>	1	89,700	-	17.47	-	forest	Vu (D2)
	<i>Pachnodus (P.) beckettii</i>	1	50,500	-	6.00	-	forest	Vu (D2)
	<i>Pachnodus (Nesiocerastus) ornatus</i>	1	101,000	-	12.00	-	forest	Vu (D2)
	<i>Pachnodus (N.) silhouettianus</i>	1	46,600	-	15.31	-	forest	Vu (D2)
	<i>Pachnodus (N.) fregatensis</i> ³	1	7,700	87%	2.00	-	low forest	En (Ala)
	<i>Pachnodus (N.) kanillali</i>	1	545,000	-	15.00	-	high forest	Vu (D2)
	<i>Pachnodus (N.) prasinus</i>	1	7,000	-	7.00	-	palm forest	Vu (D2)
	<i>Pachnodus (N.) oxoniensis</i>	1	422,800	-	3.28	-	moss forest	Vu (D2)
	<i>Pachnodus (N.) ladiguensis</i>	1	0	-	0	-	forest ?	Extinct
	<i>Pachnodus (N.) curiosus</i>	1	0	-	0	-	forest ?	Extinct

¹ GERLACH 1997; ² GERLACH 2002; ³ GERLACH 1995a

Table 4. Summary of Tables 1-3 by family

	DD	LC	Globally threatened				Nationally threatened			
			VU	EN	CR	EX	VU	EN	CR	EX
Orthopteroidea										
Phasmoptera										
Phasmidae		6								
Orthoptera										
Acrididae	3	10					1			
Eumastacidae		1								
Gryllacrididae		2								
Gryllidae		25	2				4			
Gryllotalpidae		1								
Mogoplistidae		7					3			
Myrmecophilidae			1				2			
Phasgonuridae		5								
Tetrigidae		5	2				2			
Tettigoniidae		5								
Tridactylidae		1								
Mantoidea										
Mantidae	1	3								
Dictyoptera										
Blaberidae	2	1								
Blattellidae	13	15	6				6			
Blattidae	1									
Nocticolidae			1				1			
Polyphagidae			1				1			
Dermaptera										
Pygidicranidae		1								
Anisolabididae			2				2			
Carcinophorinae	1									
Spongiphoridae		6	2				2			
	21	94	17	0	0	0	24	0	0	0
Lepidoptera										
Nepticulidae	1									
Tineidae	6	23	8	11	2		9	12	2	
Psychidae	2									
Gracillariidae	2	4	2	4			2	4		
Oecophoridae	10	8	6	1	1		6	1	1	
Blastobasidae	1	1		1				1		
Gelechiidae	8	13	1	1			1	2		
Momphidae	4	9	1	3			1	5		
Metachandidae	4	11	2	3	2		2	3	2	
Scythiridae			1				1			
Copromorphidae	1									
Alucitidae		2								
Carposinidae	1									
Epermeniidae							1			
Glyphipterigidae		2								
Plutellidae		2								
Yponomeutidae	1	1								
Lyonetidae	1			1				1		
Heliodinidae			1				1			
Immidae	2									
Hyblaeidae		1								
Thyrididae	4	3								
Pyralidae	38	57	1	2			4	17		
Pterophoridae	5	7								
Choreutidae			2				2			

	DD	LC	Globally threatened				Nationally threatened			
			VU	EN	CR	EX	VU	EN	CR	EX
Tortricidae	11	17	2		1		2		1	
Geometridae	8	17								
Uraniidae		1								
Notodontidae		1								
Lymantriidae		1								
Arctiidae	5	6	2				4	1		
Noctuidae	35	55	1				4	4		
Nolidae	8	4	1				1	1		
Sphingidae	1	8	1		1	1	2		1	1
Hesperiidae	1	4					1			
Pieridae	1	3								
Lycaenidae		6								
Nymphalidae	3	5		1		1	1	1		1
	164	272	32	28	7	2	45	53	7	2
Mollusca										
Neritidae							5			
Viviparidae				1				1		
Thiaridae		1								
Bulinidae							1			
Helicidae		1								
Cyathopomidae		2								
Hydromiidae			1				1			
Pomatiisidae		2								
Vaginulidae		3								
Ferussaciidae		1								
Subulinidae		4								
Tornatellidae		1								
Streptaxidae		18	4		2		4		2	
Succineidae		2								
Acavidae		4	3				3			
Punctidae		1								
Chronidae		1	2				2			
Euconulidae		2								
Helicarionidae		3	1				1			
Pupillidae		3								
Pupisoma		1								
Cerastidae		9	2	1		3	2	1		3
	0	61	13	2	2	3	19	2	2	3

Appendix II Invertebrate monitoring in Seychelles

The only invertebrate population estimates carried out to date have been for terrestrial Mollusca and the day-flying hawkmoths. For molluscs, a system of random quadrats has been used over the last 15 years for both leaf-litter inhabiting and arboreal species (GERLACH 1999, 2003b). The use of randomised quadrats allows the molluscs to be studied regularly without requiring sophisticated marking of location techniques and over-sampling of small areas.

Hawkmoths have been monitored in one locality, the 16ha area of the Dauban Marsh to Pointe Ramasse Tout on Silhouette island. This comprises nine ha of open habitat and 6.25ha of woodland. In this area searches were made for active hawkmoths at several times of day to provide an estimate of the total area used by this population of moths. The majority of moths were found to be feeding on one area of *Lantana camara*. In 1999 this area was visited hourly and the number of moths of each species recorded to obtain activity patterns (Fig 1). Mark-recapture studies of 20 moths were

used to obtain population estimates based on the number of moths observed and the average time taken for moths to return to the study plants. Moths, returned to the plants after 4.5 hours (range=3-6). Numbers of moths increased throughout the day, with a maximum number in July 1999 of 22 *Cephonodes hylas*, 2 *C. tamsi* and 1 *M. alluaudi*, giving a density estimate of 352 per km² for *C. hylas*, 32 *C. tamsi* and 16 *Macroglossum alluaudi*. On Silhouette, there are 10km² of optimal habitat for the bee hawkmoths and 100km² for *M. alluaudi*, giving population estimates of 3520 *C. hylas*, 320 *C. tamsi* and 1600 *M. alluaudi*. Since then, the area is visited one per day in the early afternoon during the seasons when hawkmoths are observed.

Fig 1. Activity patterns of hawkmoths in 1999

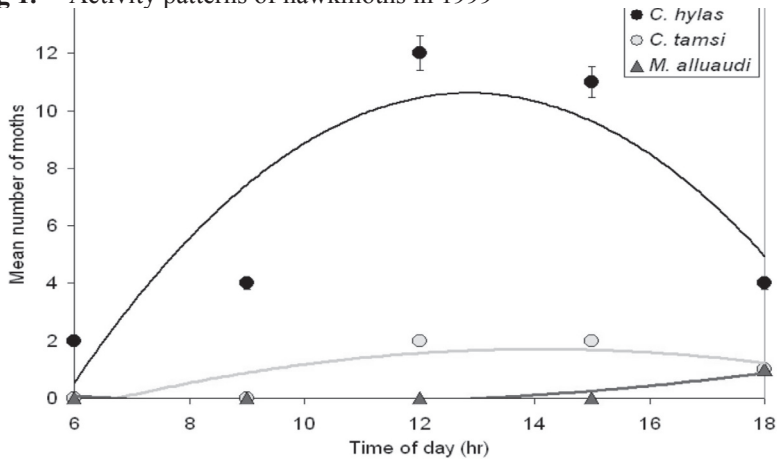
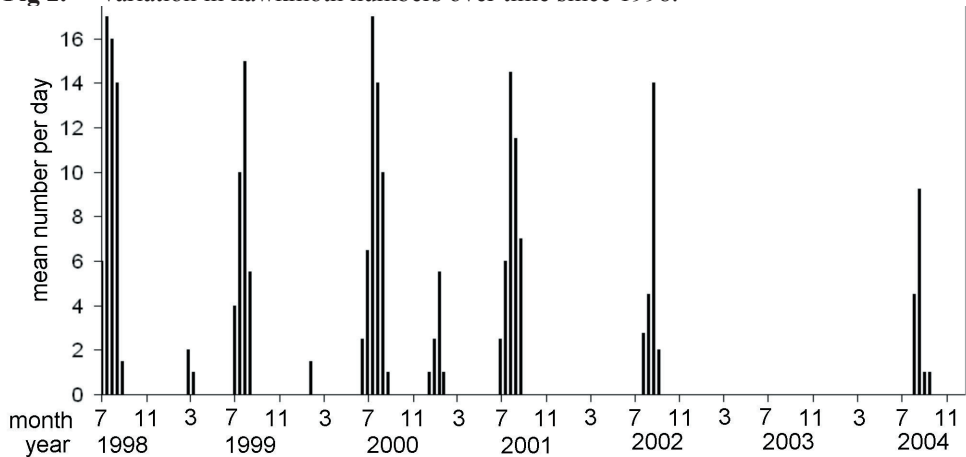


Fig 2. Variation in hawkmoth numbers over time since 1998.



Captive management of the Frigate Island giant tenebrionid beetle *Polposipus herculeanus*

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Abstract: The Frigate Island giant tenebrionid beetle *Polposipus herculeanus* is a Critically Endangered species restricted to Frigate Island, Seychelles. The ex-situ conservation programme at the Zoological Society of London and the European Endangered Species Programme are described. Captive propagation started in 1996 and has been highly successful with the programme holding 980 adult beetles by the end of 2003. Reproductive data is described and the finding of pathological infections of the fungus *Metarhizium anisopliae* var. *anisopliae* is discussed.

Key words: Coleoptera, conservation breeding, Seychelles, Tenebrionidae

The Frigate beetle (*Polposipus herculeanus* SOLIER, 1848) (Fig. 1) is one of the world's most remarkable, and endangered, tenebrionid beetles. Currently restricted to Frigate Island, Seychelles, it has a highly restricted distribution and is listed as Critically Endangered (A2e) in the IUCN Red List 2004 (IUCN 2004). In 1995 the accidentally introduced brown rat (*Rattus norvegicus*) became established on Frigate Island, initiating concerns about the potential predation threat to the native wildlife. In 1996, with the support of the Government of Seychelles and Frigate Island Private, the Zoological Society of London's (ZSL) Invertebrate Conservation Unit (ICU) was approached by the Nature Protection Trust of Seychelles (NPTS) and BirdLife International and asked to establish an ex situ captive group of Frigate beetles. As a result 47 beetles



Fig. 1 Adult Frigate beetles (photo: A. Ferguson)

were collected and transferred to ZSL in 1996 (PEARCE-KELLY 1997), and a further 20 beetles were collected in 1999 (FERGUSON 2000). The remit of the ex-situ conservation programme was to establish a proven husbandry protocol for maintaining and breeding Frigate beetles in captivity, to conduct research into their life history and to investigate disease profiles of the species.

The ex-situ programme has proved successful; its husbandry remit has been realised and it continues to provide much needed lifecycle and health information. Additional breeding groups have been established at a limited number of institutions. In 2002 European Association of Zoos and Aquaria (EAZA) committee officially elevated this initiative to European Endangered Species Programme (EEP) status. The management of the ex-situ populations is described here, summarised from the “Management Guidelines for the Welfare of Zoo Animals – Frigate Island Beetle” (FERGUSON & PAUL PEARCE-KELLY 2004).

Distribution and status

These beetles are endemic to Frigate Island in the Seychelles archipelago. Situated at 55.93°E and 04.58°S, Frigate Island is the most easterly and isolated of the granitic Seychelles group. There is some debate as to the historic range of the Frigate beetle. It was first described by SOLIER in 1848, from a specimen supposedly collected from Bengal on the Voyage of DUVAUCEL (SOLIER 1848; MARSHALL 1982). This record was refuted by GEBIEN (1922) and the beetle has not been found on the Indian mainland since. Collins (1983) puts forward a theory that the beetle could have colonised from India, as stowaways in bundles of sandragon *Pterocarpus indicus* wood. However, it seems much more credible that the specimen from ‘Bengal’ was mislabelled (M.V.L. BARCLAY, pers. comm.).

In 1869 Lt.-Col PIKE collected two specimens, apparently from his visits to Round Island, off Mauritius. Both of these (one consisting of only a head and thorax), are in the collection of the Natural History Museum, London (M.V.L. BARCLAY, pers. comm.). The beetle has not been found in this location since and the source of these specimens has also been doubted (MARSHALL 1982). The collection of B.G. NEVINSON (1852-1909) in the Natural History Museum includes six Frigate beetle specimens labelled ‘Seychelles Is.’ without further data. The first known authentic collection of the beetle from Frigate Island was in 1905, and again in 1908, by the Percy Sladen Trust Expeditions. All subsequent specimens are known to have been collected from Frigate Island and today this is the only location where the beetle exists (LIONNET 1971). Although the validity of the source location of the two earlier specimens has been questioned and despite lack of solid evidence, some authors do argue for the species once having a wider distribution, encompassing other islands in the Seychelles and possibly Round Island as well (GERLACH *et al.* 1997). The Frigate beetle inhabits forest stands and it is possible that extensive clearance of native trees for agriculture could have caused the beetle’s extinction from other islands in the Seychelles (COOKE 1997). This theory could be investigated further by researching the ground litter in likely historic range, beetles of this kind are robust and it is possible that pieces of the exoskeleton might be easily found if ground litter were sifted for extraction of beetle

parts from the substrate (M.V.L. BARCLAY, pers. comm.).

The natural vegetation of Frégate Island has been extensively altered by human activity and little is known of the island's original vegetation structure and habitat dynamics. Continuous human settlement is thought to have commenced from the early 19th century with resultant clearance of the native *Pisonia grandis* woodland to make way for plantations in the late 1800's, largely of coconuts *Cocos nucifera* (ROBERTSON & TODD 1983). Introduced species, especially the cinnamon (*Cinamomum verum*) and cashew (*Anacardium occidentale*), have now replaced much of the natural woodland (McCULLOCH 1996). Approximately 75-80% of the island is now covered with this mixed species forest (Fig. 2) and when the monsoon changes this often produces an autumnal effect on the trees, with leaves being lost creating a thick leaf litter layer which the beetles are often found in (B. SACHSE, pers. comm.).

Wild ecology and behaviour

The Frégate beetle is arboreal and nocturnal. LLOYD (1971) carried out a survey in 1971 and reported finding the beetle only 'on trees or decaying logs'. LIONNET (1971) reports that although beetles had been found on the ground 'under fallen palm leaves', he collected them from the 'cracks and holes' of trees. Captive studies confirm the beetles are nocturnal, spending the daylight hours hidden in crevices in trees, coming down to the ground to feed during the night (SLATER 2001). As well as clustering in crevices and under bark during the day beetles also hide in tree nodes and on the underside of horizontal branches where they meet the trunk (B. SACHSE pers. comm.). Predator avoidance might have been the stimulation for the evolution of this behaviour. Predators of the adults include Wright's skink (*Mabuya wrightii*) (MELLOR 2002). The larvae are taken by magpie robins and skinks (*M. wrightii* and *M. seychellensis*) (J. MILLETT pers. comm.). Adult beetles produce a chemical from defensive glands at the posterior of the beetle (MARSHALL 1982), this chemical has a musky smell and stains the skin purple/brown but does not cause any irritation (pers. obs.).



Fig. 2 Frégate beetle breeding room at ZSL, showing large and small tubs (photo: A. Ferguson)

Although sightings have occurred of beetles on a huge variety of tree species, a preference for several different tree species is shown (LLOYD 1971). As well as being found on native species like badamier (*Terminalia catappa*) the adult beetles appear to have adapted successfully to many introduced species and are found associated with sandragon, cashew, *Alstonia macrophylla* and mango (LLOYD 1971; COOKE 1997). They occur in a variety of woodland types (sandragon, mixed and coastal), but are infrequently found in scrub and coconut plantation, and are absent from grassland, agricultural areas and settlements (Gerlach 1999). Beetles are most abundant in mixed woodland dominated by mature cashew, which has heavily fissured bark (N. McCulloch, in litt. 1993). It appears that niche preference could be based predominantly on tree trunk and branch structure; species with flaky bark, fissures, cracks and crevices being favoured as they provide refuges in which to hide during the day. Mellor (2002) found the beetles had a clumped distribution, and were present more often on trees with a larger diameter (i.e. more mature trees); in mixed woodland the beetles prefer *Alstonia macrophylla*, this appears to contradict other studies as this tree species has a smooth, pale bark offering little shelter or camouflage. Other species the beetles seem to associate with are *Dracaena reflexa*, *Calophyllum inophyllum*, *Paraserianthes falcataria*, cinnamon and mango (B. SACHSE, pers. comm.). Species the beetles appear to avoid are coconut, *Ficus benghalensis* and *Artocarpus altilis*.

The beetles occur from ground level to 15m above ground (C. MELLOR pers. comm.). COOKE (1997) recorded beetles most frequently at 1.5–2m height. They are often seen aggregated in groups of up to 21 individuals when roosting during the day (LLOYD 1971; MURRAY & NICOLL 1998). Whether this is due to the availability of refuges or whether the beetles obtain some benefit from this gregarious behaviour is unknown. Being fairly large and flightless it seems reasonable to assume they have low powers of dispersal; a 10 week mark-recapture study (May-July) found that 6.5m was the mean distance beetles moved from the marking site (MELLOR 2002). The furthest a beetle travelled was 19m and half the animals were found still on their original tree.

In captivity the beetles sometimes display an unusual behaviour when being sprayed with a fine mist; standing tall, they lower their head, raise their abdomen and then ‘flick’ their body quickly from one side to the other (pers. obs.). What this behaviour serves to achieve is unknown, possibly it helps deflect water off them in the case of heavy rain or might assist with clasping onto the tree. It would be interesting to discover if this behaviour occurs in the wild.

Management in captivity

Frégate beetles are kept successfully in large colonies in captivity but at denser levels the potential risk of stress and disease affecting the population increases. ZSL uses large plastic tubs measuring 90cm length, 70cm width, 60cm height, with a large branch sticking up vertically, for populations up to 100 beetles (usually less) (Fig. 3). Large, round plastic plant containers (80cm diameter) have also been used as well as a smaller oblong glass tank. Small numbers (approximately 12) survive well and have bred when kept in smaller containers (50x20cm, and 15cm substrate depth). Frégate beetles have fused elytra and cannot fly so there is no requirement for the enclosure to

have a lid. However, they are adept climbers. A smooth surfaced vertical edge to the enclosure of at least 16cm height from the substrate is sufficient to keep the beetles inside.

At ZSL, a 'coir' substrate (based on coconut fibre) is used, mixed with layers of leaf litter and chunks of wood. Most ZSL containers have a 50cm substrate depth: the substrate needs to be at least 30cm deep to allow the larvae optimum room for tunnelling and pupating, although breeding has successfully occurred in only 12cm. The bottom of the container has holes to facilitate drainage, covered by a thin layer of pea shingle (c3-4cm) the soil substrate placed on top of this. Larval development is fastest, with the highest weight gain and the most number of instars (measured by length) in 17 weeks in a substrate consisting of 40% soil, 40% rotten wood and 20% decomposing leaves (VEEN & BERDOUNI 2003).

Frigate beetles are arboreal and are provided with 1.5–2m upright tree trunks/branches with nooks and crannies, fissures or flaky bark. Additional pieces of wood are buried completely, half buried and placed on top of the substrate, as food for larvae. Leaf litter added to the substrate provides food for adults and larvae and refuge areas for adults.

Mites can build up in the substrate and in high numbers this can adversely affect the viability of the larvae and pupae; this is thought to be the cause of one captive population dying out (R. RATAJSZCZAK, pers. comm.). Regular replacement of the substrate prevents mites from building up in large numbers, but this must be offset against the damage done to larvae and pupae whilst sorting them out from the soil. To some extent, mite level can be controlled by not allowing the substrate to become too wet. Daily inspection, prompt removal of dead beetles and regular replacement of the substrate, are important health management measures.



Fig. 3 Beetles clustering (photo: A. Ferguson)

The environmental parameters the beetles are exposed to are within the range experienced under field conditions; however seasonality effects have yet to be studied in the field and therefore have not been incorporated into management regimes. The ZSL environmentally controlled room has air temperature ranging between 25°C (night) to 28°C (day). Tub soil temperature is 22-24 °C (measured at 12cm below surface level). Relative humidity is generally 65-75 %, but can rise to approximately 95% after the tubs are sprayed. One group of beetles at ZSL is on public show in an exhibit tank, this has a similar temperature range as above but is not as humid (45-55% relative humidity).

The photoperiod is set to a 12 hour cycle, the reverse of natural daylight. From 8am-8pm red fluorescent lights are on; most insects appear insensitive to the deeper shades of red light, so it is effectively dark for the beetles (Wigglesworth 1972). From 8pm-8am, white TLD 36W/35 fluorescent lights illuminate the room, giving lux readings ranging from 1500 (top of branch) to 150 (bottom of branch, in shade). These fluorescents are in the process of being replaced with natural spectrum lights emitting 2% UVB and 10% UVA. Ultraviolet radiation has been shown to adversely affect the culturability and germination of fungal conidia of *Metarhizium anisopliae* var. *anisopliae* (BRAGA *et al.* 2001), a fungus that can kill the beetles (see below).

Newly emerged beetles are transferred into the appropriate generation enclosure. No aggression has been seen when these are transferred (pers. obs.). Experience at ZSL indicates that group structure can be mixed and changed with no problems. Always be aware of the risk of transferring disease between different groups, if any show signs of disease that enclosure should be quarantined.

ZSL has an 'on show' enclosure comprising a mixed species exhibit, housing beetles in with Seychelles millipedes (*Sechelleptus seychellarum*) and enid snails (*Pachnodus fregatensis*). This system has worked very well for the beetles and millipedes, however it is drier and less humid (45-55% humidity) than in the breeding rooms, so has not proved to be as successful for the snails. The beetles breed successfully under these conditions, however millipede density is very low (4 individuals), at higher levels the burrowing millipedes would undoubtedly disturb pupating beetle larvae.

The ZSL programme animals are kept in a dedicated room as single generation, single species groups in separate tubs (enclosures). In this way the beetles can be monitored easily and appropriate conditions for the beetles care are not compromised in any way by other species presence in the enclosure. Working practice includes certain barrier and hygiene precautions being taken e.g. wearing dedicated laboratory coats, washing hands and using gloves. In the same room are housed other Seychelles invertebrates; Seychelles millipedes (*Sechelleptus seychellarum*), enid snails (*Pachnodus fregatensis*) and Seychelles scorpion (*Chiromachus ochropus*). These require the same environmental conditions but are kept in separate enclosures.

Diet and feeding

Very little has been published on the wild diet of these beetles. Adults eat fruit and fungi (MILLET 1999) and leaves (MELLOR pers. comm.). Observations of the larvae (and their presence as indicated by their distinctive large bore holes) show they will feed on most types of rotten, decaying wood, including; sandragon, cashew (LLOYD 1971),

Pisonia grandis, *Terminalia catappa*, *Albizia lebbek* (GERLACH 1996) and also coconut logs (N. McCULLOCH, in litt. 1993). The current ecologist on Frigate has not observed larvae in the coconut stumps although larvae of the rhino beetle use this resource (B. SACHSE, pers. comm.). Larvae have even been found in the thatch of the house roofs when the thatch was removed and replaced in 2003 (B. Sachse, pers. comm.).

In captivity, a variety of fruit and vegetables (produce) is offered including; apple, carrot, potato, sweet potato, sweetcorn, mushroom, cucumber, banana and lettuce. Two or three of these items are offered daily, on a rotational basis. Adults have been seen eating the bark of branches and leaf litter in their enclosure (pers. obs.). A variety of types of broadleaf tree species leaf litter is used such as London plane (*Platanus x acerifolia*), horse chestnut (*Aesculus hippocastanum*) and birch (*Betula* sp.). The litter is frozen for 24 hours or immersed in water for a few days in order to minimise the introduction of pests. Soaking the litter may increase palatability (I. ROMA, pers. comm.). They are also reported eating moss, lichen and bark chippings (K. VELTMAN, pers. comm.). A nine week study comparing one group of beetles fed on the latter diet with another group fed the same diet but additionally offered fruit and vegetables found no significant weight difference between the two groups (VEEN & BERDOUNI 2003). Captive beetles in Mauritius are reported to have eaten fungi, and the larvae 'any rotten wood' (GERLACH 1996).

The larvae require dead wood to feed on, appearing to prefer the more decomposed wood (pers. obs.). The larvae will burrow right inside food items and decaying wood, and pupae have been found in chambers made in decomposing wood (pers. obs.). In an experiment to test whether the larvae expressed any kind of preference between wood types, HARDING (2002) found there was no significant difference between larval association with horse chestnut, sycamore (*Acer pseudoplatanus*) and palm wood (*Trachycarpus fortunei*). He found that larvae reared on sycamore alone had better survivability, larger weight gain and increase of body length over 79 days than larvae reared on the other two types. The reasons for this can not be determined as there are undoubtedly a number of interacting factors affecting digestibility such as water content, stage of decay and type of mycological breakdown.

On two occasions a beetle has been observed cannibalising a large pupa (pers. obs.). In one case the pupa had been seen on the substrate surface earlier that day, indicating all was not well with it (they rarely stay on the surface); then later on a beetle was seen eating this from the anterior whilst it was still alive. This might indicate these beetles eat animal protein in the wild (by scavenging) and raises the suggestion that a protein rich food should be provided in the diet. At Riga Zoo the beetles are also offered granulated cat food. Both adults and larvae have been observed eating this (I. ROMA, pers. comm.), suggesting that the larvae might also scavenge for protein. It would be valuable to carry out further investigations in this area.

These animals are extremely sensitive to pesticide chemicals. As a precaution against potentially harmful chemicals all produce is peeled, washed and the top 2cm of carrots are discarded (as this area is most likely to be contaminated). Water is provided in shallow, small containers (4cm diameter), containing soaked cotton wool to prevent drowning. The cotton wool is changed once weekly or more often if necessary. The

beetles are watered and the enclosure sprayed daily with a fine mist (reverse osmosis, filtered rain or filtered tap water) providing droplets of water the beetles can drink from in the branches.

Captive behaviour

Frégate beetles will live in a large group with little aggression (pers. obs.). During the day (light hours) they cluster tightly together in crevices on branches or under bits of wood on the substrate, they prefer to climb upwards in daylight hours if provided with the opportunity. It is possible that clustering density is related to the availability of crevices.

LEE (2003) observed a beetle 'butt' and push another out of the way with lifting head movements, whether this related to food or territory is not known. On occasions beetles have been seen interfering with a mating pair (SLATER 2001). They will cluster round a food source (pers. obs.), and the food needs to be in large chunks and sufficiently dispersed throughout the enclosure to ensure that many individuals have access to it. At higher densities these interactions are likely to become more frequent.

Reproduction

Little has been recorded of the reproduction of this species in the wild. Frégate beetles were first hatched and reared in captivity by Mr R. POPE, at the Natural History Museum (NHM), London in 1977. 12 live adult specimens were sent to the NHM and ova were present on pieces of sandragon bark which were included in the consignment. The beetles and eggs were kept in a propagator at 29.5°C and 80% relative humidity. Several larvae were reared and preserved at different instar stages, and one adult emerged (MARSHALL 1982). Carl JONES in Mauritius has also bred captive Frégate beetles (GERLACH 1996). Beetles have bred regularly since 1998 at ZSL and all members of the EEP breed this species successfully.

The beetles show no obvious sexual dimorphism. Morphometric measurements collected at ZSL of known sex beetles has been statistically analysed and shows no significant difference in size between the sexes, so this can not be used as a diagnostic tool for sexing (SLATER 2001; LEE 2003).

Very little courtship has been observed; mating occurs more frequently at night (dark hours) (SLATER 2000), mostly in the early hours of darkness (Harding 2002), as would be expected given that this is the main activity period for this species. Males initiate 72% of matings, but females have some control over mating as 80% of failures were due to female rejection (the other 20% being due to disturbance by another individual) (SLATER 2000). Mating has been observed on the substrate surface but 60-80% of observed matings occur in the tree branches (HARDING 2002; LEE 2003). Copulation has been observed lasting 21 minutes (pers. obs.). A possible form of mate guarding has been observed, where the male remains standing over the female for approximately 20 minutes after mating (Lee, 2003).

On one occasion after a mating pair was disturbed, the female was seen to have a white, thread like structure protruding from her rear (pers. obs.). Beetles have also been observed producing a long white strand in a blob of clear liquid from their

posterior (Fig. 4), then immediately turning to eat this discharge, and others also joining in to eat (pers. obs.). Samples taken and examined microscopically contained a tubular body or plug, with approximate dimensions 0.2x5mm (observed by phase contrast magnification x10 and x40). Within and around the plug were numerous live, very motile spermatozoa, with very long flagella and small heads (Fig. 5) (MACGREGOR, pers. comm.), confirming that these exudates are sperm plugs or spermatophores. How long after mating the sperm plug is expelled is unknown.

Mating frequency appears not to be particularly high given the density of beetles in enclosures at ZSL. In 24 hours total time spent observing beetles (made during their active period over 6 weeks, 300 beetles in 4 tubs) only 17 matings were recorded (T. Lee, pers. comm.). Under controlled captive conditions there appears to be no seasonality of breeding (pers. obs.) and it is unknown whether this species shows breeding seasonality in the wild. Monitoring mating partners over a number of years has shown that males and females mate with different partners (Ferguson 2002), suggesting a polygamous mating system. No post-natal parental care has been observed.

The eggs (Fig. 6) are oblong, approximately 1.5-2mm long and a pale yellow in colour. They are most often laid on or near wood just under the substrate surface. Occasionally eggs have been seen on the wood branching above the substrate and also on the substrate surface, not near any wood. The interval between egg laying and hatching has been observed to be less than 2 weeks at an average temperature of 24° Celsius (pers. obs.) and five days at 26-27°C. The high temperatures produced white, motionless larvae which turned yellow by the fourth day and on the fifth day bored holes into the soft rotten wood provided (I. ROMA, pers. comm.).

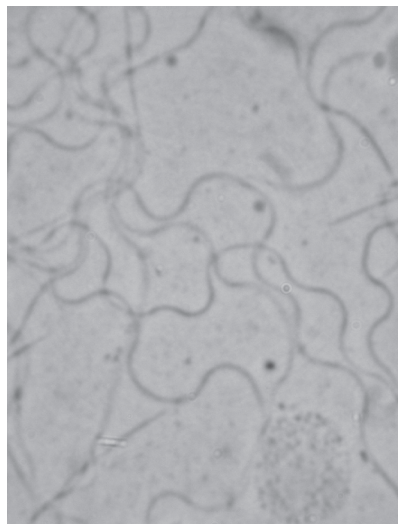
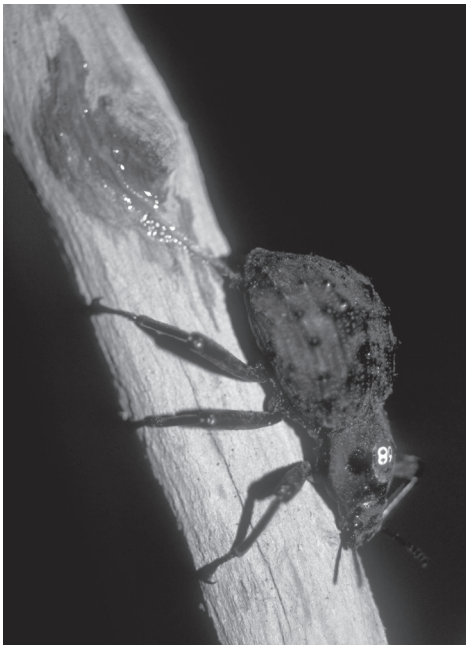


Fig. 4 Female passing sperm plug
(photo: A. Ferguson)

Fig. 5 Spermatozoa x400
(photo: A. Ferguson)

The larvae spend all their time beneath the substrate surface. They tunnel in the soil eating fruit, vegetables and rotten wood, as well as the substrate medium (Ferguson 2002). There are seven larval instars (Fig. 7) (Marshall 1982), the last reaching 5cm in length (Ferguson 2002). At this stage the larva excavates a chamber in the substrate approximately 2x4x3cm high in which it remains motionless for an average of 9 days (n=34) before pupating (Fig. 8). After 17 days (n=35) it metamorphoses into a beetle, pale brown and lying on its back. It gradually darkens off, turns the right way up and then tunnels its way to the surface to emerge an average of 8 days later (n=42) as a fully formed adult. The whole development process from the larva making a chamber to the adult beetle emerging takes an average of 34 days (Ferguson, in prep.).

If pupae are disturbed i.e. the chamber collapses or they are removed from the chamber, they are unlikely to continue development successfully (Ferguson 2002). An obvious sign a new beetle has emerged is the evidence of a tunnel. Occasionally, a new emerged beetle will retreat to its tunnel during the day (light hours) within the first 24 hours after emergence. When they leave the tunnel, they are often seen to climb as high as possible on the branches provided. Adults have also been observed emerging from rotting wood (pers. obs.; I. ROMA, pers. comm.), so can make chambers in decomposing wood as well as soil substrate.

Wild collected beetles have produced next generation adults 10 months after their arrival and other generations have emerged in 9 months (FERGUSON pers.obs). Larvae (1cm long) were seen in a tub seven and a half weeks after the first two beetles of a new generation emerged and were placed in a breeding tub, thus the adults are fertile and able to breed by 4-6 weeks after emergence with a generation time of 7-10 months (larvae take 6-8.5 months to emerge as adults).



Fig. 6 Frigate beetle eggs (photo: A. Ferguson)

Fig. 7 Frigate beetle larvae (photo: R. Williams)

Fig. 8 Frigate beetle pupa (photo: A. Ferguson)

Longevity

Longevity in the wild is unknown. Two founder individuals, collected as adults of unknown age for the ex situ breeding programme, survived over seven years in captivity, although the average age appears to be approximately half this (pers. obs.).

Health and disease

Post-mortem examination of a number of beetles at ZSL has shown an association with a fungal infection *Metarhizium anisopliae* var. *anisopliae* (Fig. 9). This is a known entomopathogen capable of causing a fatal systemic mycosis (A. CUNNINGHAM, pers. comm.). Identifying the source of this infection is complicated. *Metarhizium anisopliae* is a common mycopathogen of soil insects in temperate regions (Charnley 1997) and is probably ubiquitous throughout the tropics as well (J. NICKLIN, pers. comm.). The source of infection could originate from the coir substrate and leaf litter used in the beetles' enclosures, or, the original wild collected adults may have been exposed to this fungus in situ before being transferred to ZSL. So far this fungus has not presented on post mortem examination of any other invertebrate species at ZSL, further suggesting a pre-existing association.

The situation is further complicated by the use of this fungus as a biocontrol for a number of invertebrate species (the method of infection is discussed by Clarkson & Charnley 1996). It has been found in *Oryctes* sp. beetles (Scarabaeidae) in Kenya and was also introduced to Mauritius in the 1930s as part of investigations into control methods for the sugar cane white grub *Clemora phillophaga* (Scarabaeidae) (Greathead 1971). It would be valuable to investigate whether in the past this biocontrol has been used on Frégate, or other islands in Seychelles. In the 1928 Seychelles Department of Agriculture's 'Annual Reports on Agriculture' it notes "Fungus parasites are helping in insect control [referring to scale insects]. A programme is being drawn up for the introduction of other fungus parasites and predators" in the 1933 edition it says "Another parasitic fungus was obtained from India" (J. Gerlach, pers. comm.). There is a possibility it has been used on rhino beetles (*Oryctes monoceros*) in coconut plantations on the Seychelles (Gerlach pers. comm.), although there is no documented record of its use in Lionnet's (1959) review of the biological control of agricultural pests in the Seychelles.



Fig. 9 *Metarhizium anisopliae* on necropsy examination (photo: A. Pocknell)

There are thought to be different subspecies (transgenic strains) of *Metarhizium anisopliae* var. *anisopliae*, with differing host specificities (J. NICKLIN, pers. comm.). Identification of the strain found at ZSL and compared to that found (if any) in the fresh substrate and on Frégate Island would help elucidate the picture. Further collaborative investigations are planned between ZSL and Birkbeck College, London University.

It has not been established whether this fungus occurs in wild beetles. One in situ wild Frégate beetle has been observed with a suspected fungus growing around the joints implying there might be a presence in the wild population (R. LUCKING, pers. comm.). The beetle was not collected, so the fungus identification remains unknown. It would be valuable to carry out disease profiling on the wild beetle population and would be an essential action should translocation be considered as a conservation option.

Fortunately, this infection appears not to be particularly virulent in healthy adult Frégate beetles. The mortality rate in the population as a whole is relatively low and not all deaths are attributed to this organism. Of 112 post-mortems in 2002, 30% were positive for the fungus, suggesting a low pathogenicity of this particular fungus isolate in the Frégate beetle (ELLIOT 2003) and it is possible that the individual beetle only succumbs to this fungal infection if it is compromised or stressed in some other way (J. NICKLIN pers. comm.). Death rates and causes are constantly monitored at ZSL. Prompt removal of dead individuals, preferably before generation and dispersal of conidia, and regular replacement of the substrate should help minimise exposure to fungi. Larvae have also died infected with *Metarhizium anisopliae* var. *anisopliae*. Having intimate contact with the substrate, it is to be expected that the larvae would be affected, and this might provide an explanation for the relatively few adults that emerge from the hundreds of larvae seen in the tubs (pers. obs.), although there could be other causal factors.

Other post mortem findings include prolapse and possible egg binding, *Geotrichium candidum* in larva (this is thought to be a secondary agent infecting larva after trauma and not the primary pathogen), possible gout, rhabditoid nematodes (from a non-pathogenic genus) in an adult beetle abdomen, *Aspergillus niger* and *Candida pelliculosa*.

Generation size

It appears that some of the populations at ZSL show a slight decrease in average size through the generations. However, there is great variation in the size of the wild collected adults so investigations are currently being carried out to indicate whether this is a significant difference in size or not.

MARSHALL (1982) reports that the single F1 generation bred at the NHM was noticeably reduced in size compared to the wild collected parents. She speculated on a number of factors which might have caused this: insufficient food, a growth inhibiting effect from salicylic acid in the willow bark provided for larval food and presence of symbiotic eugregarine protozoa in the guts of the larvae although these protozoa might assist with the digestion of wood (A. POCKNELL, pers. comm.). At ZSL individual adult beetles have had their faeces screened and the results were negative for gregarines. It would be valuable to investigate whether the wild population carries this protozoan.

Other possibilities that may cause size changes are high levels of lectins (sugar binding proteins that have an inhibitory effect on growth; GURJAR *et al.* 2000), the increased level of fruit and vegetables offered in captivity might cause the shortening of development time and protein level in the diet might be too low when compared to a wild diet which may include carrion. It has also been postulated that keeping larvae at high density may adversely affect their viability and might cause smaller adult size (I. ROMA, pers. comm.). This theory requires further investigation.

Population management

The total population in Europe in captivity at 31st December 2003 was 980 individual adults in five institutions (Table 1). All beetles originate from those bred at ZSL, where beetles have now been bred to the fifth generation. The Frigate beetle breeding project was initiated in 1996 and became an official European Endangered Species Programme (EEP) in October 2002. The EEP coordinator is currently Amanda FERGUSON at ZSL.

Beetles wild collected in 1996 are kept separate from those collected in 1999 and different generations are kept separately. Daily checks are made for new emerged beetles which are removed from the enclosure, marked with an identification disc (Fig. 12) and a series of standardised physical measurements taken before being transferred to a different tub holding beetles of the same generation. A coding system is employed, consisting of: generation/year founders were collected e.g. F2/96 is the second generation from the 1996 collected beetles. It is essential that accurate records are kept of each adult's emergence and death. Individually labelling beetles allows data to be collected on age at death, which is useful when looking at disease epidemiology. Institutions participating in the EEP are asked to carry out post mortem examinations on deceased specimens so the disease status of the populations can be monitored.

The Frozen Ark project, initiated in July 2004, is aimed at preserving DNA and tissue samples of endangered species to ensure basal genetic data is not lost. Stored under optimum conditions this genetic material provides a resource for research and conservation as well as informing best population management practice for still living but threatened species. The EEP programme has provided 30 post mortem larval specimens, representing the generations closest to the original wild founder groups (15 larvae of F2/96 and 15 of F1/99). For more information see http://www.nhm.ac.uk/news/items/frozen_ark270704.html.

Conservation Status

Being endemic and having such a restricted distribution the Frigate beetle is considered especially vulnerable to extinction from events such as the introduction of disease or alien species and natural disasters. It is listed in the IUCN Red List and the Seychelles Red Data Book as 'Critically Endangered A2e' (NPTS 1997; IUCN 2004) Critically Endangered (A2e). In the early 1970's and 1980's the beetle was reported as 'fairly common' or 'abundant' (LIONNET 1971; LLOYD 1971; COLLINS 1983). A basic sample survey of 50 trees in each of six areas in August 1993 determined that the beetles were 'not common in the main plantation areas below the 10m contour', despite mature

trees being present (McCulloch 1993).

Although previously brown rats had occurred sporadically on Frégate, it was their colonisation in 1995 that caused the conservation community great concern. In 1996 Birdlife International staff (LUCKING & LUCKING followed by MURRAY & NICOLL) initiated monthly sample surveys of the beetle numbers which continued regularly until 2001, then on an ad hoc basis in 2002 (J. MILLET, pers. comm.) using a similar protocol to that used in 1993 (STRACHAN & DUNN 1997). Lower altitude sites consistently held the lowest number of beetles and an apparent seasonal variation in beetle abundance was noted, with numbers being highest between November-May, the wetter season, possibly due to a change in behaviour increasing their detectability (LUCKING & LUCKING 1997). Increases in August 1998 may have been partly due to the beetles clustering under an increased number of nest boxes for the magpie robins (MURRAY & NICHOLL 1998). Subsequent monthly transects showed a significant decline in beetle abundance between March 1996 and December 1999 attributed to predation by rats (MILLET 1999; PARR 1999). In 2000, Frégate Island was effectively de-ratted by poison baiting (SHAH 2001). Measures are in place to prevent the accidental re-invasion of rats, which remains an ever-present possibility.

GERLACH (1999) calculated a total population estimate of 74,521–104,940 based on data collected in 1997 by STRACHAN & DUNN (1997) (61,490 in mixed woodland, 11,583–38,610 in *Pterocarpus* woodland, 1,448 – 4,840 in coastal woodland and some scarce sightings in other habitats). He notes that this estimate is ‘vulnerable to errors in density estimate, area calculations and the biased distribution of survey sites’. The Birdlife monthly transects in 2001 (post rat eradication) showed an increase in beetle abundance (J. MILLET, pers. comm.). Two recent studies have attempted to estimate total population size. A combination of the McCULLOCH/Birdlife methods in 1999 and 2002 (before and after rat eradication) estimates the population at 57,060 ($\pm 9,038$) in 1999 and 50,390 ($\pm 3,288$) in 2002 (difference not significant) (GERLACH 2005). Transects in sandragon and mixed woodland in May-July 2002 estimate a population size of 22,750 with the total population being not much higher than this value as the beetle ‘hardly occurs’ in habitats outside the sample types (C. MELLOR, pers. comm.).

The above surveys have been carried out during the day, which might bias the results towards recording daytime visibility levels rather than numbers present. The variation in methodology, effects of observer bias and variations in beetle seasonal activity pattern mean it is difficult to compare the results of these surveys over time. It would be valuable to develop a more robust, standardised methodology for assessing population size. Surveying at night might yield some valuable results when the beetles are more active and dispersed.

In 1998 Angasana wilt (a fungal disease caused by *Fusarium oxysporum*) was discovered attacking sandragon trees on Mahé (BOA 2002). The subsequent spread to Frégate resulted in a die off of most of the Island’s sandragon trees by 2004 (M. MACQUITTY and B. SACHSE, pers. comm.). This is likely to have a profound effect on vegetation dynamics as sandragon is a major woodland component and is one of the principal Frigate beetle associated tree species. Many dead beetles can be found in these dead stands and they appear to be dispersing out to less favoured habitat (B.

SACHSE, pers. comm.).

One potential conservation measure is the translocation of Frigate beetles to other islands in their considered former range such as Cousin, Cousine or Aride in Seychelles, and Round Island, off Mauritius (COOKE 1997, LUCKING & LUCKING 1997). This course of action could only occur if the target islands have suitable habitat remaining, or restored habitat that satisfies the beetles' ecological requirements, as well as being free of alien predators. Disease profiling of the beetles would need to be fully investigated before any translocations were carried out. Any reintroduction, release or translocation programme would have to comply with the IUCN guidelines, which have been developed 'to help ensure that re-introductions achieve their intended conservation benefit, and do not cause adverse side effects of greater impact' (see <http://iucn.org/themes/ssc/pubs/policy/reinte.htm>).

The beetle remains vulnerable due to its restricted range, so still warrants conservation focus. Health related investigations are essential when considering the possibility that the translocation of Frigate beetles to former historic range islands might become a future conservation option.

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Appendix I. Other Frigate Island invertebrates maintained at ZSL

Husbandry & captive management at ZSL - environmental parameters

- Room temperature range 25-28°C. Substrate temperature range 22-24°C.
- Room humidity 65% (65-75%).
- Spraying and watering daily is carried out using reverse osmosis water which has been left standing in the room for 24hrs to warm up and thus avoid ‘cold shock’.
- Photoperiod set to a 12 hour cycle on reverse lighting. From 08.00–20.00hrs red fluorescent lights are on; from 20.00-08.00hrs white TLD 36/W/35 fluorescent lights provide illumination, giving lux readings of 1500–150 in different parts of the room. These are in the process of being replaced with natural spectrum lights emitting 2%UVB and 10% UVA.

Seychelles millipedes (*Sechelleptus seychellarum*(DESIARDINS, 1834))

Husbandry: The millipedes are kept in large tubs or smaller glass tanks with a thick layer of substrate (coir and leaf litter in layers). They spend most of the light hours underground. They are active in the dark and will occasionally climb branching if provided. A variety of food is offered and placed on the soil surface. Potato, sweet potato, apple, carrot, cucumber, mushroom, sweetcorn, lettuce, and banana. Where possible the food is peeled in case of pesticide contamination. All the food is washed in reverse osmosis water. Cuttlebone is also given in small chunks and it is also ground up and mixed into the substrate to provide extra calcium.

Observations: Average width and length of adult males is 13.4mm and 176mm; and females 14.5 and 189 mm (n=10 in each case). Average weights; males 31.5g (n=9) females 34.1g (n=10) – different individuals from the previous. The original adults received from the wild all died within 2 years, so longevity is assumed to be 2-3 years. They moult underground. They can be handled but about 50% of the time will ooze a

chemical which stains hands yellow. Young of 2cm were seen in the soil 11-12 months after the adults arrival.

Other holders: Bristol, Shaldon, Dudley, Drusillas, Rotterdam, Artis, Poznan & Riga.

Enid snails (*Pachnodus fregatensis* VAN MOL & COPPOS, 1980)

Husbandry The snails are kept in plant propagators 22x33x17cm high. A 5cm layer of coir is provided with moss covering ~½ of the area. The snails are fed ‘partula diet no 13’ spread on a perspex slide placed on the substrate as well as washed lettuce and a piece of peeled fruit/veg (potato, sweet potato, apple, carrot, sweetcorn & lettuce). Food is changed and the propagator lids cleaned every other day. Cuttlebone pieces are provided. The propagator vents are kept open and fine plastic mesh siliconed over the holes to prevent escapes. Deaths have occurred due to room overheating (max 38°C).

Observations: Eggs are laid in batches of approximately 50 under moss.

Other holders: Martin Mere & Riga.

Seychelles scorpion (*Chiromachus orchropus* KOCH, 1838)

Husbandry: The scorpions are kept singly; unless in a breeding pair. Adult pairs are kept in glass tanks 30x60x30cm with a 5cm layer of coir substrate. Stones, wood and cork bark are provided for refuge. A shallow water container is provided. Sub-adults are kept singly in plastic containers (16x28x10cm) with a shallow (2cm) layer of soil, with bark, plastic tubing or ½ flowerpots for refuge and water containers (as above). They are fed weekly with crickets usually, but also waxmoth larvae, mealworms or locusts. Smaller ones are fed more frequently. Containers are watered and sprayed whenever necessary and the substrate kept with a gradient of wetness. The scorpions are not disturbed at all whilst moulting and for a few days afterwards.

Observations: Breed fairly easily. After introducing male and female mating occurs soon (hours or days later). Young have been produced 10 months after being introduced. Between 60-100 young are born, white, and crowd on the female’s back. They stay on the females back for at least 4-6 weeks; however some stay on for a few weeks after this (some have also been seen on the male!). The first moult has been seen 12 days after birth. To get maximum numbers reared they need to be separated from each other and the parents, or cannibalisation occurs (albeit at a low rate). Slight sexual dimorphism visible. Number of pectin teeth varies between 8-10 and can be different on the left and right side of the same individual. A number of adults and young are being sent to Museum Nationale d’Histoire Naturelle, Paris scorpion expert, Wilson Lourenço to conduct further lifecycle and development research.

Other holders: Bristol, Poznan & MNHN Paris.

Table 1. Frigate beetle EEP summary

	London	Poznan	Bristol	Artis	Riga	TOTAL
1996	43	0	0	0	0	43
1997	34	0	0	0	0	34
1998	56	0	0	0	0	56
1999	117	10	12	0	0	139
2000	285	?	13	20	0	318
2001	361	?	26	20	0	407
2002	380	0	124	14	15	533
2003	619	30	130	18	183	980

The impact of rodent eradication on the larger invertebrates of Fregate island, Seychelles.

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Abstract: Island populations are often regarded as being threatened by introductions of alien rodents. In 2001 brown rats (*Rattus norvegicus*) were eradicated from Fregate island, Seychelles. A study of population sizes of the larger invertebrate species potentially at risk from rat predation was carried out in 1999. This covered the giant tenebrionid beetle (*Pulposipes herculeanus*), Seychelles giant scorpion (*Chiromachus ochropus*), Fregate enid snail (*Pachnodus fregatensis*) and the Fregate streptaxid snail (*Conturbatia crenata*). Population estimates were repeated in 2002, a year after the rat eradication had been completed. Comparison of these estimates indicates that there has been little change in beetle and scorpions populations, both of which are considered to be Vulnerable on the basis of restricted ranges. The snails have declined significantly. The snail population declines are suggested to be a result of the broadcast use of the molluscicidal rodent poison Brodifacoum during the rat eradication. *P. fregatensis* is regarded as Endangered as a result of this population decline and *C. crenata* may be extinct.

Keywords: *Chiromachus*, conservation, *Pachnodus*, *Polposipes*, rodent eradication

The impact of introduced mammals on the ecology of islands has been widely reported in the context of the population declines of vertebrates, especially birds. Comparatively little information is available concerning invertebrates. Exceptions to this include accounts of the declines of weta crickets (*Hemideina* and *Gymnoplectron* species; BROWN 1997; GREEN 2002) on the off-shore islands of New Zealand and the *Partula* snails in Polynesia (COWIE 1992). In 1995 brown rats (*Rattus norvegicus*) colonised Fregate island, Seychelles and the early stages of the process of population establishment recorded (THORSEN *et al.* 2000). Over the past 20 years there have been numerous alien mammal eradication projects carried out on islands around the world, these have been reported to result in dramatic recoveries of habitat and threatened vertebrates but little consideration has been given to the impacts of rodent removal on invertebrates (EASON & SPURR 1995), exceptions are the documentation of population increases in tree wetas (*Hemideina crassidens*) following rat eradication (BROWN 1997). Invertebrates have generally been assumed to be immune to poisoning by supposedly mammal specific poisons (SHIRER, 1992). Residues of Brodifacoum poisons have been detected in arthropods (MORGAN *et al.* 1996; OGILVIE *et al.* 1997; PAIN *et al.* 2000) and other invertebrates, including gastropods (Morgan *et al.* 1996). The effect of Brodifacoum on molluscs was investigated in more detail by GERLACH & FLORENS (2000a&b), indicating that some species are highly vulnerable to poisoning, and concern was raised over the potential impacts on molluscs on Fregate island.

Fregate island is the seventh largest island in the Seychelles group (219

hectares) and the ninth highest (125m above sea level). Given the depth of the marine channel between Fregate and the other granitic islands it has probably been isolated from the rest of the Seychelles islands for the last 12,000 years. Fregate has retained an unusual fauna with significant populations of taxa now rare on the other Seychelles islands (e.g. the giant scorpion *Chiromachus ochropus* KOCH, 1838), species now extinct elsewhere (e.g. giant tenebrionid beetle *Polposipes herculeanus* SOLIER, 1848) and distinctive endemic species (e.g. the endemic snail *Conturbatia crenata* GERLACH, 2001). All of these species persist on what is at first sight one of the most disturbed and un-natural of the Seychelles islands. By the 1970s Fregate was recognised as supporting an important fauna even though only the conspicuous species such as the Seychelles magpie robin *Copsychus seychellarum*, Seychelles fody *Foudia seychellarum* and giant tenebrionid beetle were mentioned in popular publications (LIONNET 1971). Until the late 1990s research on the island was been limited to studies of the birds (CROOK 1961; KOMDEUR 1996; GRETTON 1990-2; BURGER & LAWRENCE 2001) and reptiles (RENDAHL 1939; GARDNER 1987) and small collections of invertebrates (GEBIEN 1922; HIRST 1911; BENOIT 1978) and plants (ROBERTSON 1987).

The first description of Fregate in 1787 gives an impression of scrub habitat and low trees (FAUVEL 1909), resembling islands such as Aride which were, and are still, covered in *Pisonia granids* woodland. The scrubby nature of the habitat persisted until the late 1800s at least (PIKE 1873). Pike mentioned a more developed woodland type on the plateau. The presence of an endemic woodland species of snail (*Conturbatia crenata*) suggests that this was a significant, if localised, habitat in the past (GERLACH 2002).

During the early 1900s the island was settled and cleared for coconut (*Cocos nucifera*) plantation with vanilla (*Vanilla planifolia*) established on stakes of *Pterocarpus indicus*. These stakes subsequently grew and now form the main woodland areas on the island, with *Pterocarpus* woodland replacing the natural forest habitat. To some animal species the new *Pterocarpus* woodland may have represented an improvement on the very open, dry *Pisonia* woodland of the past. The more structurally complex *Pterocarpus* woodland, its fissured bark and its high input of dead wood may have allowed the native fauna to survive despite the loss of the natural habitat. This fauna may be threatened by introduced animals: the Indian mynah (*Acridotheres tristis*) is reported to be a competitor and predator of the magpie robin (McCULLOCH 1996), house mice (*Mus musculus*) have been present and abundant on the island for many years, cats (*Felis catus*) were present from the late 1950s but were eradicated in 1982 (TODD 1982). Brown rats (*Rattus norvegicus*) colonised the island in 1995, apparently in cargo for the island's plantation (McCULLOCH 1996). There are no quantified published data on the impacts of these species and their significance cannot be assessed at present. Alien species also include a wide variety of plants as well as animals; *Chrysobalanus icaco* is an aggressively invasive species in exposed areas and *Alstonia macrophylla* is a recent but already significant invader.

The invasion by rats was seen as a potential threat to the endemic invertebrate fauna and *ex situ* captive breeding was initiated by the Nature Protection Trust of Seychelles (NPTS) and the Zoological Society of London (ZSL) to safeguard the

survival of the most vulnerable species until such time as the rats had been eradicated (ANON. 1996; FERGUSON & PEARCE-KELLY 2005). Giant tenebrionid beetles, enid snails, giant millipedes and giant scorpions were collected and transported to ZSL in 1996 (LUCKING & LUCKING 1997) and 1999 (GERLACH 1999b).

The giant tenebrionid beetle is the best known of Fregate's invertebrates. Historically it was present in the Mascarenes and probably widespread in Seychelles but declined as a result of habitat destruction (GERLACH *et al.* 1997). Although natural habitats persisted on Fregate in the 19th century the beetle remained overlooked and presumably occurred at low densities, by 1905 it was more abundant or conspicuous and significant numbers were collected (GEBIEN 1922). Since then it has remained an abundant part of the island's fauna. The presence of the Fregate enid snail *Pachnodus fregatensis* Van Mol & Coppo, 1980 was first reported in 1972 (as *P. ornatus*) (LIONNET 1972). It was not described as an endemic species until 1980, based on specimens collected in 1972 on banana trees along the Rivière Bambou (VAN MOL & COPPOIS 1980). In 1989 it was found to be locally common in agricultural areas of the plateau but despite searching only a single individual could be found in woodland (pers. obs.). The giant scorpion (*Chiromachus ochropus*) is known from four islands in Seychelles and the Mascarenes (where it is now extinct); a record from Zanzibar is believed to be an error (Gerlach 1999a). Fregate is the only island where it is abundant. There are no data on historical abundance on the island Fregate; it was first recorded there in 1838 (KOCH 1838) and has been recorded regularly since then. The Fregate streptaxid snail (*Conturbatia crenata*) snail is known from a single specimen found in *Pterocarpus* woodland in 1999. It is Fregate's only endemic genus and represents an interesting biogeographical anomaly (GERLACH 2002). This status makes it the most important Fregate species for biodiversity conservation.

The location of rats in 1995 prompted an eradication attempt a few months after the first rats were seen. The extensive use of traps caught many rats but was suspended when birds were also caught. The use of anti-coagulant poisons was also tried at the same time but the poisoning of a magpie robin led to the suspension of this method. Eradication was changed to a policy of containment using live traps, this was also unsuccessful and rats rapidly spread across the island (THORSEN *et al.* 2000). In 2000 an eradication project was undertaken by the Seychelles Government's Division of Environment using broadcast poisoning the anti-coagulant Brodifacoum (MERTON *et al.* 2001). Poisoning controls and eradication of rats have been tried elsewhere without noted losses of reptiles or invertebrates, however, there are no published studies specifically addressing the impact on these animal groups. Anecdotal reports of a Brodifacoum poisoning programme in Mauritius report a decline in numbers of native molluscs and studies of the Seychelles fauna indicated that poisoning represented a risk to *Pachnodus* snails (GERLACH & FLORENS 2000a&b).

A visit was made to Fregate in 2002 to assess the impacts of the rat eradication on the invertebrate fauna. The results of this study are reported below and compared to data collected by the author in 1999 (prior to rat eradication). Giant millipedes were studied as part of a wider study reported in GERLACH *et al.* (2005).

Methods

In order to determine whether or not habitat change was an influence on any invertebrate populations vegetation composition and structure studies carried out in 1999 were repeated in 2002. Habitats can be categorised as *Pterocarpus* woodland (*P. indicus* dominated), coastal woodland (mixed native coastal species), mixed woodland (*P. indicus* and *Anacardium occidentale* abundant), scrub (*Chrysobalanus icaco* and *Panicum maximum*), coconut plantation, agricultural (including open grass) and settlement (Fig. 1). All of these represent un-natural habitats created through agricultural or conservation plantation, they are therefore in habitat blocks and are easily distinguished in the field. In each habitat area the number of trees over 2m tall were recorded and identified to species in 10 haphazardly positioned quadrats of 5x5m.

Population density estimates were made for each of the invertebrate species previously suggested to be of conservation concern (GERLACH 1997). Tenebrionid beetles were studied using a survey method used on the island since 1993 (McCulloch unpublished data; LUCKING & LUCKING 1997). 20 trees were haphazardly selected in each habitat survey quadrat and the number of beetles visible to 5m above ground counted to give a measure of abundance per tree (with a record of tree species). This method of surveying tenebrionid beetles is strongly influenced by the vertical movement of beetles on the trees. In order to provide an indication of possible changes in the vertical distribution of beetles in the two surveys one tree in each quadrat was observed with binoculars for 30 minutes. The location of each beetle was recorded in visually estimated 5m bands. Snails (*Pachnodus fregatensis* and *Conturbatia crenata*) and giant scorpions were also counted by searching under all moveable rocks and logs in the quadrats. *C. crenata* occurred at extremely low densities; in order to obtain statistically meaningful density estimates an additional 100m² were searched near each quadrat, giving a total search area of 125m² in each site.

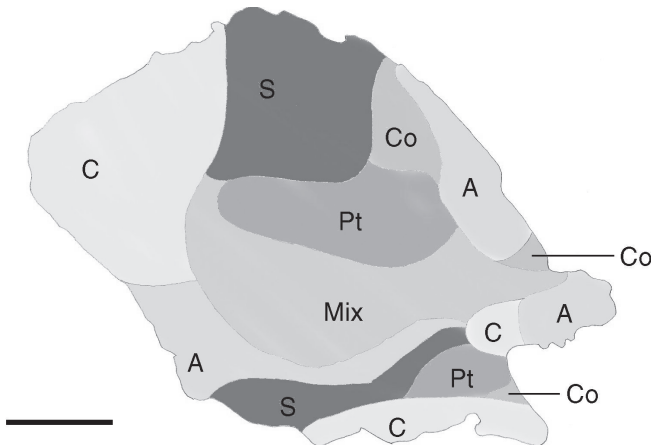


Fig. 1 Habitats of Fregate island in 1999. A = agricultural and settlement; C = coconut plantation; Co = coastal; Mix = mixed; Pt = *Pterocarpus indicus*; S = scrub. Scale bar 300m

Only the scorpions show sexual dimorphism; KRAPELIN (1896) recorded that males had relatively elongate claws (length:width=1:0.6) compared to females (length:width=1/0.8) and had tails longer than their abdomens (female tails being shorter); in the present study adults were sexed to investigate differences in sex ratios. Snails were divided into age classes: hatchling (<2 whorls), juvenile (<6 whorls), subadult (full sized but without a developed shell lip) and adult (with a fully developed lip).

Results

The composition of these habitats and their approximate areas (estimated from aerial photographs and data in KOMDEUR 1996) are shown in Table 1. No significant habitat change had occurred other than an increase in tree density and area of coastal woodland, at the expense of agricultural areas and the increase of coastal tree species in scrub and mixed woodland. The areas of habitat changed significantly over this time, with coconut plantations being replaced by coastal woodland.

The abundance of the invertebrate species in different habitats is summarised in Fig. 2 and 3. Statistically significant changes (as indicated by paired-sample t tests) are highlighted. The vertical distribution of beetles showed a peak in numbers below 10m, there was not notable change in the two survey periods. For *Pachnodus fregatensis* snails the population structure in September 1999 showed an adult bias (67%) with relatively few subadults (22%) and juveniles (11%). This pattern is similar to that seen in other *Pachnodus* species (GERLACH 2001b). A higher proportion of juveniles and hatchlings may be detectable in the main breeding season which would be expected to coincide with periods of high rainfall (November-March). In October 2002 adults could not be located and the population was subadult biased (67%). *Conturbatia crenata* was found as a single individual in 1999 in a *Pterocarpus* woodland quadrat. This gives a maximum population density of 400 per hectare in 1999. Despite careful searching in 2002 this species could not be located.

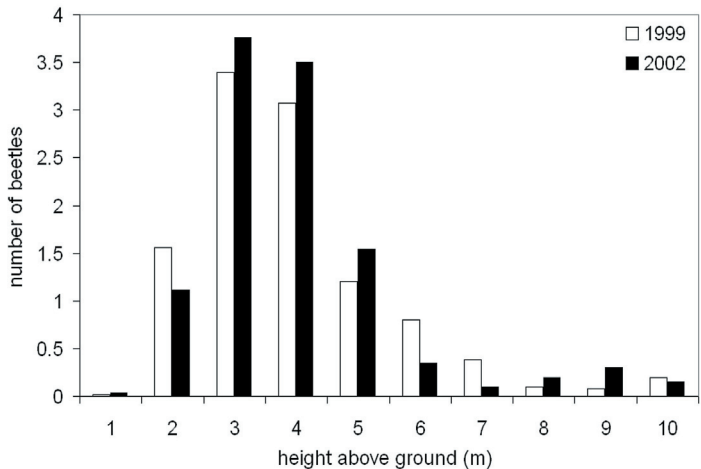


Fig. 2. Vertical distribution of *Polposipes herculeanus* beetles in 1999 and 2002

Table 1. Habitat areas and tree densities on Fregate.

Year	Habitat	<i>Artocarpus</i>	<i>Pterocarpus</i>	<i>Cocos</i>	Density of trees (per hectare)		Alstonia	coastal spp.	other	Area (ha)
1999	<i>Pterocarpus</i>			100	150	100				13
	coastal		1,700					3,200	100	8
	mixed	100			1,100	267	100	100		10
	Scrub				400	100	1,000			60
2002	Coconut			4,000	100	100			200	92
	Agriculture								300	15
	Settlement		1600		133	100		67	67	5
	<i>Pterocarpus</i>									13
	coastal	267		133				10,000	333	14
	mixed				1,200	300	200	400	300	10
	Scrub				400	100	2,000	400	100	54
	Coconut			4,100				2,800		90
	Agricultural							100	100	15
	Settlement								400	5

Table 2 IUCN status assessments (criteria from IUCN 2001)

Species	Population	2002	change	Occupancy (km ²)	area	Status
<i>Ptilosipites herculeanus</i>	57,060±9,038	50,390±3,288	-12%	2.0		VU D2
<i>Chloromachus ochropus</i>	16,875±4,554	17,686±7,025	-20%	2.0 (Fregate), 9.0 (all)		VU D3
<i>Pachnodus fregatensis</i>	5,910±5,407	4,730±880	-87%	2.0		EN A2a
<i>Conturbatia crenata</i>	5,200±125	Extinct ?	>-80%	0.1		CR A2a

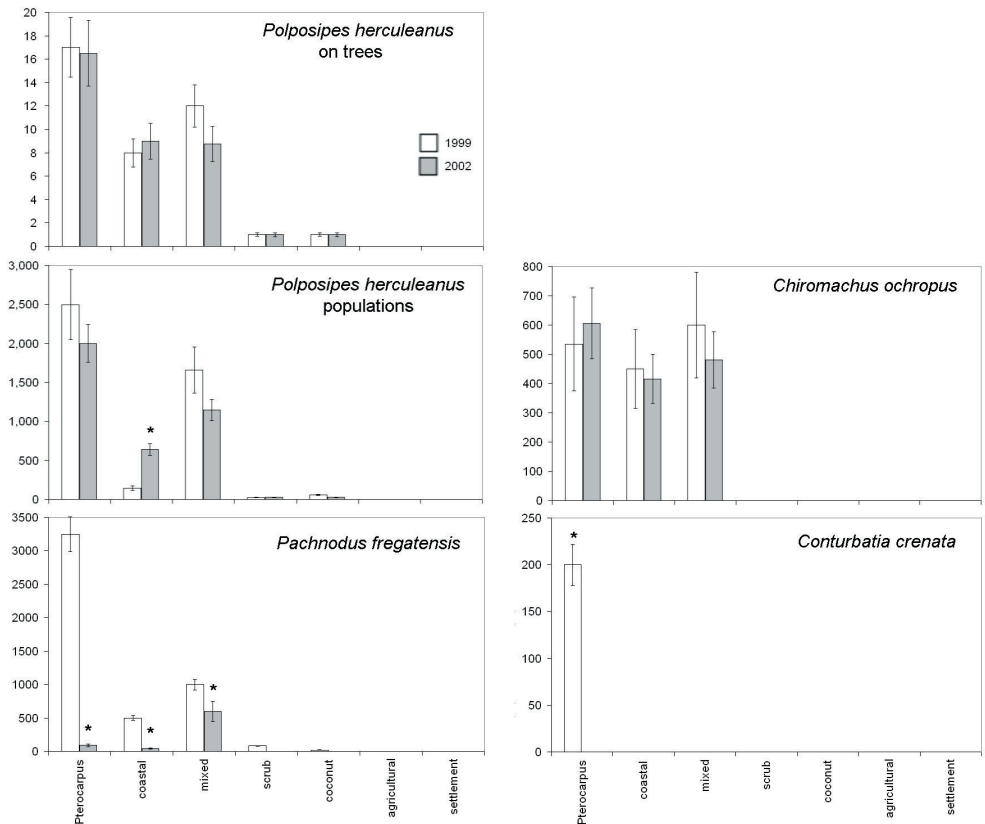


Fig. 3. Population density changes of studied invertebrates in 1999 and 2002. Significant differences ($P < 0.05$) marked with asterisks. Vertical axis is numbers per hectare except for *Polposipes herculeanus* on trees where it is numbers per 20 trees.

The giant scorpion population in 1999 was strongly female biased (1:4.5 $n=11$ adults). The adult to juvenile ratio varied locally, disturbed areas being adult biased (9:1 $n=20$) compared to undisturbed areas (1:3.5 $n=20$). In 2002 the female bias was still present (1:9 $n=10$), the adult to juvenile ratio was 1:2.5 ($n=14$) in the undisturbed area and 1:3.8 in the previously disturbed area ($n=24$).

Discussion

The invertebrate populations studied here showed no overall pattern of population change. In the case of the giant tenebrionid beetle there is little change in overall population although increases in population density occurred in coastal woodland as this has matured and improved as a habitat. As a slow moving, flightless

and apparently defenceless beetle this species was feared to be at risk from rat predation and there were reports of rat-chewed elytra (MURRAY & NICOLL 1999), although this has not been verified. The threat posed by the rats was investigated by beetle population monitoring by BirdLife International staff on Fregate from 1996 (LUCKING & LUCKING 1997). In 6 sites in the north-eastern half of the island all beetles visible on 20 trees were recorded. In 1998 one of these sites was lost to harbour development (MURRAY & NICOLL 1998); the remaining 5 sites continue to be monitored. The 1996-7 data showed considerable variation and indicate a strong seasonal effect of beetle activity which complicates data interpretation. Subsequent data have not been made available except in a summarised form (MURRAY & NICOLL 1999). This summary was used to demonstrate a catastrophic population decline but is difficult to interpret due to observer differences and statistical problems (J. MILLET pers. comm.), a major component of the variation reported appears to be due to seasonality (LUCKING & LUCKING 1997). The reported decline has been presented as a linear regression (MURRAY & NICOLL 1998) showing a significant decrease in the number of beetles recorded ($y=214.04-3.3487x$; $R^2=0.388$; $P<0.05$). This analysis fails to take into account the change in survey areas following the development activity on Fregate. If the disturbed sampling areas are excluded from the 1996-8 data the corrected regression fails to provide any evidence of significant overall population decline ($y=34.067-0.4091x$; $R^2 = 0.195$; $P>0.05$). Increases in the beetle population size in 2001, within 12 months of rat eradication has been reported (HILL 2001). Although this is only a short time after rat eradication, as the tenebrionid beetle larvae take 6-8.5 months to mature and generation time is 7-10 months (FERGUSON & PEARCE-KELLY 2005) a sustained increase from mid 2001 is possible, although not apparent in the 2002 monitoring data. Thus the impact of rat presence and eradication remains equivocal for this species. The continued improvement in natural habitat on Fregate through ongoing replanting should enable populations of this and other invertebrates to recover or to continue expanding. It is believed that the giant tenebrionid beetle was once present in coastal habitats of most of the Seychelles islands and it could be reintroduced to some of its former range. As definite records are lacking, reintroduction would only be appropriate to areas with suitable habitat and where it can be demonstrated that a reintroduction would not have an adverse effect on any existing indigenous species, such criteria are met for the islands of Aride and Cousine as these have abundant soft dead wood from coastal woodlands and studies of dead-wood inhabiting invertebrates indicate the absence of large wood boring beetles with the exception of widespread elaterid beetles (KELLY & SAMWAYS 2001; MEEGAN & GERLACH 2000; PHILLIPS 2001).

No significant change is apparent in the giant scorpion population overall. The area of *Pterocarpus* woodland disturbed (by relatively frequent rock movement within the past year) in the late 1990s was adult biased in 1999 but in 2002 was not notably different from undisturbed habitat. This suggests that juveniles are vulnerable to disturbance, possibly by increasing the risk of predation. Rat predation on the giant scorpion has been reported (K. MURRAY & M. NICOLL pers. comm.) although this has not been substantiated. Fregate supports the only remaining significant population of *C. ochropus* scorpions, the causes of declines in this species on other islands remain to

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be identified and research into the ecology of this species continues.

The Frigate enid snail has suffered a major decline in population, falling to 13% of the 1999 population by 2002. This occurred in all habitats although not evenly; in *Pterocarpus* woodland populations were reduced to 3%, 14% in coastal woodland and 60% in mixed woodland. The species was very scarce and localised in 1988 (pers. obs.) but was abundant in 1996 (R. LUCKING pers. comm.) and in 1999 it was found to be highly abundant in woodland areas. The apparent population increase between 1988 and the mid-1990s corresponds to a major ecological change in the removal of free-range chickens and pigs (McCULLOCH 1996), both of which would have acted as major predators of the snails. No evidence of predation by rats was observed in 1999 and none has been reported. *Conturbatia crenata* also appears to have declined substantially since 1999. As only a single specimen was located in 1999 any comparisons are necessarily limited, but the failure to locate this species in 2002 despite intensive searching suggests that the species may be extinct or at very reduced population levels. The rat eradication programme in 2000 resulted in the dispersal 35kg/ha of Brodifacoum bait (MERTON *et al.* 2001). GERLACH & FLORENS (2000a&b) demonstrated that Brodifacoum is highly toxic to snails, a dosage of 0.002mg was sufficient to kill *Pachnodus silhouettanus* in 4 days, higher dosages resulting in death within 12 hours; indicating that Brodifacoum is highly toxic to snails. *C. crenata* is a carrion feeder (GERLACH 2002) and this would make it highly vulnerable to indirect poisoning following consumption of other poisoned snails. The broadcasting of Brodifacoum is probably the main cause of the population decline in *P. fragatensis* and the possible extinction of *C. crenata*.

The changes in populations recorded here are due to two main factors; habitat change and direct poisoning. Habitat change has been significant between 1999 and 2002. The replacement of the original dry habitats by *Pterocarpus* woodland may have allowed population increases in species such as the giant tenebrionid beetle and the rapid habitat restoration carried out in the last 5 years is resulting in further habitat improvements. This restored habitat is a mixture of naturally regenerating *Pisonia grandis* woodland and planted areas dominated by *Terminalia catappa*, *Thespesia populnea*, *Heritiera littoralis* and *Ochrosia oppositifolia*. The natural distribution of habitat can only be guessed at and the composition of the original coastal woodland is unknown. Even following habitat restoration most invertebrate species will remain at risk of extinction due to their restricted ranges (most can be considered Vulnerable or Endangered under IUCN Red List criteria - Table 2).

The lack of any apparent population increases in supposedly rat-vulnerable invertebrates since the rat eradication project may indicate that rat predation was not a significant cause of mortality in 1995-2000. The 1995 invasion was reported to be the first presence of rats on the island, however, there is evidence to the contrary. In 1962 it was reported that "war has been waged on the cats and rats on Frigate by both the Department of Agriculture and the owner, who is anxious to preserve his island's heritage" (DAWSON 1965). In February 1985 a rat was observed in a hotel room, coinciding with a rat eradication campaign using the anti-coagulant Warfarin. On the basis of these reports it would appear that rats were present from the 1960s, either sporadically or at low levels, possibly controlled by cats. Following eradication of

cats in 1982 (TODD 1982), rat numbers may have increased to a level where they were noticed around the hotel, prompting eradication. The population present in 1985 appears to have been successfully eradicated as no rats were recorded for the next 10 years.. In the context of this possible coexistence of the fauna with sporadic or low-density rat populations it is worth noting that although the Seychelles islands do not naturally have mammalian predators they are not naturally predator-free; there are significant populations of predatory molluscs (Gerlach & Bruggen 1999), reptiles and crabs. The endemic fauna has evolved in the context of these predators and anti-predator defences are apparent in many species, such as the high reproductive potential of *Pachnodus* snails (Gerlach 2001b) and birds (Gerlach 2001a).

The variable patterns of response to the eradication of rats on Fregate island indicates that eradication programmes involving the use of poisons need to take into consideration the potential impacts of the species present in the target areas. Conservation measures need to distinguish between the requirements of different animal phyla and resist the temptation to consider ‘invertebrates’ as a single group with responses that can be extrapolated from data on a narrow range of arthropods alone.

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The hawkmoths (Lepidoptera: Sphingidae) of Seychelles: identification, historical background, distribution, food plants and ecological considerations

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Abstract: The Sphingidae (hawkmoths) deserve greater attention in ecological research and conservation programmes in Seychelles because of their role as pollinators as well as components of food chains: a number of native plants, including several endemic species, display sphingophilous traits. Threats against the native Sphingid fauna include habitat destruction, the spread of invasive alien plant and animal species, artificial lighting and deliberate killing by humans. The history of research on Seychellois Sphingids is summarised, distribution and host plant records are reviewed and updated, and a key is provided for the identification of the adults of the fourteen species.

Key words: *Batacnema*, *Cephonodes*, *Macroglossum*, *Temnora*, *Nephele*,

Introduction

Because of their size and, sometimes, vivid colour patterns, both as larvae (caterpillars) and adults, the hawkmoths (Lepidoptera: Sphingidae) are often perceived as charismatic insects by humans. Yet, surprisingly little attention has been paid to them in biological and ecological research and biodiversity monitoring programmes in Seychelles, although elsewhere they are becoming a growing focus of attention: recent studies have ranged from the biomechanics of flight (e.g. ELLINGTON 1996) and the biophysics of organismal transparency (YOSHIDA *et al* 1997) to herbivore-induced responses in plants, such as the release of volatiles elicited by fatty acid-amino acid conjugates in the oral secretions and regurgitant of Sphingid larvae (HALITSCHKE *et al* 2001), and pollination biology (e.g. NILSSON *et al* 1985; NILSSON 1988) as well as ecological perspectives (e.g. HABER & FRANKIE 1989). The tobacco hawkmoth *Manduca sexta* (LINNAEUS, 1763) is widely used as a “laboratory” and “experimental” animal in the United States and elsewhere (e.g. DAVIS *et al* 2001). The sphingid fauna of another tropical archipelago, the Galapagos in the Pacific, was reviewed recently (ROQUE-ALBELO & LANDRY 2002). The perceived difficulty of identifying specimens, the rarity of the small number of endemic species and the nocturnal habits of most members of the group may have contributed to the neglect of Sphingidae by ecologists in Seychelles, but failure to realise the importance of pollinators in conservation programmes has probably also played a role. The aim of the present paper is to provide a starting point for further studies by: (1) providing a user-friendly, non-technical, identification key to the adult moths of the fourteen Sphingid species recorded from the islands; (2) recapitulating the history of observations and taxonomical work on Seychellois Sphingids from the end of the nineteenth century to the present; (3) summarising the known distribution and host plant records; and (4) pulling together the various ecological and conservation considerations that can be the basis for research and monitoring. Detailed taxonomic

treatment is not included. Identification keys to the larvae and pupae and the detailed biology of individual species will be published separately (MATYOT, in preparation).

Methods

This paper is essentially a review of the scattered previously published work supplemented with information in various unpublished reports as well as field data on biology, ecology, behaviour, etc. gathered opportunistically from 1975 to 2005. In addition, whenever the opportunity arose, caterpillars were collected and reared in the laboratory. The nomenclature adopted for the Sphingidae follows KITCHING & CADIOU (2000), while that of the host plants follows FRIEDMANN (1994) and ROBERTSON (1989), except where indicated otherwise.

Identification key to adult hawkmoths

The Sphingidae are medium to large, stout-bodied, powerful, fast-flying moths with narrow forewings, between 20 and 60 mm long in Seychelles, and hindwings that are much shorter. At rest the wings point backwards, creating an arrow-head shape. In most species the abdomen is streamlined and tapers to a point (it is blunt-ended in *Acherontia atropos*). The antennae are thickened and have a pointed hook at the tip. The larvae are large caterpillars that have a “caudal horn” (sometimes reduced to a small spine) at the back, dorsally, on the 8th abdominal segment. In the following key to adults of the Sphingidae known to occur in Seychelles, the colour patterns referred to are those seen when the insects are viewed dorsally:

- 1. Wings mostly without scales (scales lost during first flight) and therefore transparent, apart from dark veins, margins and tips 2
Wings covered with scales and therefore not transparent 3
- 2. Abdomen yellowish green, with a dark red transverse band near the middle (segments 4 and 5) *Cephonodes hylas virescens*
Abdomen reddish brown *Cephonodes tamsi*
- 3. Yellowish skull-like pattern on black background on thorax; emits squeak-like sound when disturbed *Acherontia atropos*
No skull-like pattern on thorax; does not emit a squeak-like sound when disturbed (*Hippotion osiris* may emit a faint hiss) 4
- 4. Part of hindwings distinctly pink in colour 5
No part of hindwings distinctly pink in colour 8
- 5. Pale area of hindwing crossed by 4-6 black lines (corresponding to veins) 6
Pale area of hindwing not crossed by black lines 7
- 6. Forewing with silvery white band from near base to tip, passing very close to the trailing edge (dorsal or inner margin); series of longitudinal silvery spots, in twos, on each side of central line along back of abdomen *Hippotion celerio*
Forewing with dark brown band from near base going towards tip; no silvery white markings on forewing or on abdomen *Hippotion aurora*
- 7. Base of abdomen with two black bands on each side; greenish brown streak along forewing *Hippotion osiris*

- No black bands at sides of base of abdomen; no greenish brown streak along forewing *Hippotion eson*
8. Hindwings predominantly yellow or orange 9
Hindwings not predominantly yellow or orange 10
9. Prominent anal tuft present *Macroglossum alluaudi*
No anal tuft present *Batocnema cocquerelii aldabrensis*
10. Forewings with a complicated “camouflage” (variegated or marbled) pattern of olive green, pink, purple, etc. *Daphnis nerii*
Forewings without variegated pattern of olive green, pink, etc. 11
11. Forewing with a large creamy white band from the apex of the forewing to the first third of the dorsal margin; pink antennae *Hippotion geryon*
No creamy white band along forewing; antennae not pink 12
12. Wings predominantly grey with black lines; abdomen with alternate pink and black lateral bands (each segment pink in front, black behind) *Agrius convolvuli*
Wings predominantly brown with obscure darker bands; no pink and black bands along the sides of the abdomen 13
13. Relatively small species (forewing less than 3cm long); forewing greenish brown with obscure darker bands, without white discal dot *Temnora fumosa*
Not particularly small (forewing more than 3.5cm long); forewing ochreous brown with obscure darker bands, with white discal dot *Nephele leighi*

History of research

The first records of Sphingidae from Seychelles are pictorial rather than in writing: hawkmoths feature in two of the surviving 45 paintings that the British botanical artist Marianne NORTH (1830 -1890) painted during her stay in the islands from 13th October 1883 to 23rd February 1884. Painting no. 459 in the NORTH Gallery at Kew Gardens in the U.K., entitled “*Wormia* [= *Dillenia*] and *Flagellaria* in the Seychelles”, shows a specimen of *Hippotion osiris* with proboscis uncoiled resting on a *Dillenia ferruginea* leaf, while no. 482, “Two trailing plants with lizard and moth from Ile Aride”, depicts a specimen of *Hippotion eson* resting beside the plants *Abrus precatorius* and *Sarcostemma viminalis* and a green gecko of the genus *Phelsuma*.

The first known observations on the Sphingidae of Seychelles are those reported by Henry Whatley ESTRIDGE, who was Collector of Taxes in the British colonial administration in the early 1880s, including at the time of Marianne NORTH’s visit. In the privately-published “Six years in Seychelles” (1885) he mentioned six recognisable hawkmoths: “I have caught in my house [on Mahé] the death’s head [= *Acherontia atropos*] (very common). I have had half a dozen in the breeding cage at once. The caterpillars abound on all sorts of trees and shrubs. The convolvulus [= *Agrius convolvuli*] (very common). Very frequently we have had five or six flying about our dining room when we were at dinner – they, of course, being attracted by the light. The large and small elephant, [presumably *Hippotion osiris* and *H. eson* respectively]; the oleander [*Daphnis nerii*] (rather common); the humming bird [possibly *Macroglossum alluaudi*, but Scott, the entomologist on the second Percy Sladen Trust Expedition to the Indian Ocean, used the name “humming-bird hawk moths” in his diary for *Cephonodes*

hyla virescens – see below, under that species]; and once, when (I was) walking in the woods, a black caterpillar stuck to my trousers; but, having no breeding cage at the time, I let it go – a thing I have often regretted doing. It was a charcoal black, with stripes of a glossy black.” The identity of the black caterpillar ESTRIDGE found is not certain.

Macroglossum alluaudi was not named until it was collected in 1892 by the French entomologist Charles ALLUAUD and described by JOANNIS (1893). This species was referred to again by JOANNIS (1894), who mentioned another specimen collected by Father PHILIBERT (real name Jean-Marie MEYNET), as well as all the other species listed by ESTRIDGE (1885) plus two others, the bee hawkmoth *Cephonodes hyla virescens* and the smoky Temnora, *Temnora fumosa peckoveri*, both of which had also been collected by Father PHILIBERT. The American naturalist William Louis ABBOTT collected Sphingidae during his two trips to Seychelles in 1890 and 1892-1893 but according to HOLLAND (1896) he found only the three common species *C. hyla virescens*, *A. convolvuli* and *A. atropos* collected on Mahé. Up to then, only the Sphingidae of the granitic islands had been investigated, but in 1895 the German Alfred VOELTZKOW visited the atoll of Aldabra and collected two additional species for Seychelles that were reported upon by Aurivillius (1909): the harlequin hawkmoth *Batocnema cocquerellii* var. *aldabrensis* and *Hippotion geryon*. Next, Edmund MEADE-WALDO, travelling on the yacht *Valhalla* in 1906, collected Sphingidae on Mahé only. His specimens were identified by HAMPSON (1908), who found only four of the common widespread species previously reported: *A. atropos*, *D. nerii*, *H. osiris* and *C. hyla virescens*.

There followed the two Percy Sladen Trust Expeditions to Seychelles, in 1905 and in 1908-1909, arguably the most important scientific expeditions to investigate the biodiversity of the islands. Lepidoptera, including Sphingidae, were collected during the first mainly by John Stanley GARDINER and Thomas Brainbrigge FLETCHER, and during the second mainly by Hugh SCOTT and John FRYER. Apart from adding new species to the Seychellois Sphingid faunal list, the two expeditions added to the knowledge of the distribution within Seychelles of many previously known species. Fletcher (1910) added *Hippotion celerio* and *H. aurora* from the “outer”, coralline, islands while Fryer (1912) reported on a specimen, obtained on the granitic island of Silhouette, that he referred to as “*Nephele hespera*”. While *N. hespera* (Fabricius, 1775) is known from South and South-East Asia (PITTAWAY & KITCHING 2004) and Australia (Moulds 1996), JOICEY and TALBOT (1921) recognised the Seychellois species to be a new one, which they named *N. leighi*, basing their description on another specimen collected on Mahé in 1913 by the South African George F. LEIGH. Meanwhile, in 1911, also on Mahé (LEGRAND 1966), Hans Paul THOMASSET had collected a bee hawk moth that was recognised much later by GRIVEAUD (1960) to be a new species, *Cephonodes tamsi*, bringing the number of Sphingid species known to occur in Seychelles to its present total of 14.

Later collections of Lepidoptera from various islands of Seychelles, such as those by the Italian Carlo PROLA on Aldabra and Cosmoledo in November 1953 (BERIO 1956) and French Lepidopterist Henry LEGRAND in both the granitic and coralline islands in 1956 and 1959-1960 (LEGRAND 1966), did not add any new species, although the latter contributed new distribution and host plant records. From January to April 1968 Jay C. SHAFFER of George Mason University, USA, collected “approximately 10,000

specimens of Lepidoptera ... representative of about 29 families and about 227 species” on Aldabra, but no Sphingidae have been reported from the very scant reports published on this extensive material (SHAFFER 1974). During the period September 1971-August 1972 Dawn W. FRITH caught nearly 100,000 specimens of Lepidoptera using light traps on Ile Picard, Aldabra (FRITH 1979), but only two species of Sphingidae were present in the catches, *A. convolvuli* and *Hippotion geryon*, the latter of which had not been found since it was first collected by VOELTZKOW in 1895. Between February 1976 and July 1977 Marilyn WALKER, too, carried out work on the Lepidoptera of Aldabra: “Small collections of a few larger moths apparently unrecorded from Aldabra in LEGRAND’S revision were made” (PRYS-JONES, unpublished, 1977), but this work was unfortunately never written up and published, although the intention was expressed to produce “short notes” on “larval feeding plants of some Aldabran moths” and “Aldabran hawk moths”.

Distribution and host plants

Most of what we know of the inter-island distribution of the Sphingidae of Seychelles is due to the data summarised by LEGRAND (1966) drawn from his own work and that of previous authors. Knowledge in this field is expected to expand with ongoing biodiversity monitoring programmes on an increasing number of islands. Scant attention has been paid to hawkmoth-habitat associations, however, possibly because most observations have been based on moths drawn to lights in or outside buildings at night, with few records of flower visitation, etc. in natural surroundings. In the granitic islands there is a need to scrutinise the altitudinal range of species, most currently available data being derived from observations at or near sea-level. It is also necessary to verify possible phenological (seasonal) trends in the populations of the different species, especially in connection with the prevailing monsoons and the attendant rainfall regimes, and to ascertain the status of Seychelles in relation to the migratory routes of hawkmoths. BOWLER & HUNTER (2001) refer to *A. convolvuli* on Aride island as “a regular migrant during the north-west monsoon”; certainly most, though not all, observations of this species on Mahé have been made during this period (November-February) (MATYOT, unpublished data).

The following abbreviations are used in the species accounts below:

E, F = common name in English (E) and French (F)

G, C, IO, W = distribution in the granitic Seychelles (G), in the coralline Seychelles (C), elsewhere in the Indian Ocean (IO), and worldwide (W)

Numbers of metres (e.g. 90m) refer to altitude, i.e. height above sea level. Except where otherwise indicated, LEGRAND (1966) and VIETTE (1996) are the sources for information on distribution outside Seychelles. Only host plants recorded in Seychelles are listed, except in a few cases to illustrate particular aspects of feeding habits such as specialised “feeding syndromes” or to suggest potential food plants when the ones in Seychelles are not known. Authorities for host plants are mentioned only in cases where the present author has not confirmed their validity first-hand. Species are listed in alphabetical order for ease of reference, rather than as per taxonomy.

Acherontia atropos (LINNÉ, 1758)

[E = death's head hawkmoth; F = sphinx tête-de-mort]

G = **Mahé** (JOANNIS 1894; HOLLAND 1895; HAMPSON 1908; FLETCHER, 1910; FRYER, 1912; LEGRAND, 1966; pers. obs.: larvae on food plants and adults at light, including in Victoria, up to 300m), **Anonyme** (Jean-Claude WOODCOCK, pers. comm., 2004: caterpillar on *Tabebuia pallida*), **Silhouette** (pers. obs.: larva on *Tabebuia pallida* above La Passe on 12th August 1990 & at Grebau in October 1991; Justin GERLACH, pers. comm. 2004: sightings on 1st March 2001 and 20th June 2001), **Praslin** (pers. obs.: larvae on *Tabebuia pallida* between Baie Ste Anne and Anse Marie-Louise, 1987), **La Digue** (FLETCHER 1910; Hans MALICKY, pers. comm., 1998), **Marianne** (HILL *et al* 2002.: larva on *Stachytarpheta urticifolia* in October 1999), **Arde** (Evans & Hobro 2004: larva on *Datura metel* in June 2004).

C = not recorded from the outer, coralline, islands

IO = Madagascar, Comoros, Mauritius (incl. Rodrigues), Réunion, Socotra

W = Afrotropical & Palearctic regions

Host plants: *Stachytarpheta urticifolia* (Verbenaceae), *Clerodendron thomsonae* (Verbenaceae) [LEGRAND (1966) as “*C. ugandense*”], *Tabebuia pallida* (Bignoniaceae), *Momordica charantia* (Cucurbitaceae), *Solanum melongena* (Solanaceae), *Datura metel* (Solanaceae) (on Arde (EVANS & HOBRO, 2004)), *Brugmansia candida* (= *D. candida*) (Solanaceae), *Coleus* sp. (Labiatae), *Merremia peltata* (Convolvulaceae).

In Seychelles, as elsewhere, the adult moth enters beehives to feed on honey (pers. obs. at Mon Plaisir, above Anse Royale, Mahé).

Agrius convolvuli (LINNÉ, 1758)

[E = convolvulus hawkmoth; F = sphinx du liseron]

G = **Mahé** (JOANNIS 1894; HOLLAND 1895; FRYER 1912; LEGRAND 1966; pers. obs.: at light and foraging from 50m at Hermitage to 350m at La Misère), **Silhouette** (FRYER 1912; Justin GERLACH, pers. comm. 2004: sightings on 1st April 1999 & 4th September, 2002), **Arde** (BOWLER *et al* 1999), **Cousine** (GERLACH, undated).

C = **Alphonse** (GERLACH, undated; quotes Ron & Gill GERLACH as recording a caterpillar); **Farquhar** (FLETCHER 1910); **Aldabra** (FRITH 1979: 8 specimens were caught over a 12-month period (September 1971-August 1972) by means of a Heath light trap set up for 2-8 nights per month on Picard Island – two other light traps failed to catch any; there are two specimens in the Aldabra insect collection, one labelled: “Accommodation block, Station, West Island [=Picard], 12th March 1976”, the other unlabelled)

IO = Madagascar, Comoros, Mauritius (incl. Rodrigues), Réunion, Chagos (BARNETT & EMMS 1999), Sri Lanka, Andaman Is. (FLETCHER 1910), Christmas I. (MOULDS 1986)

W = Afrotropical, Palearctic, Oriental and Australian regions.

Host plants: *A. convolvuli* is associated with plants of the family Convolvulaceae, including the sweet potato, *Ipomoea batatas* (WATERHOUSE 1998), throughout its range. In Seychelles only two larval food plants (both Convolvulaceae) have been recorded: a caterpillar was observed feeding on *Ipomoea cairica* at La Rosière on Mahé on 6th January 1998 (Neil MATHIOT & Terence LAWRENCE, pers. comm.) and another was found on *I. mauritiana* at Mare aux Cochons on Mahé on 2nd January 1999 (pers. obs.). *I.*

cairica is a known food plant in Australia (MOULDS 1981). Two host plants mentioned in earlier literature need to be confirmed: FLETCHER (1910) reported finding caterpillars on “poc-poc” on Farquhar; “pokpok” (current official spelling) is one of the Creole names of *Passiflora foetida* (Passifloraceae), known to occur in the granitic Seychelles and, as “var. *hispida*”, on Assomption in the outer islands (FRIEDMANN 1994). LEGRAND (1966) for his part reported obtaining an adult moth from a caterpillar found at Mont Fleuri on Mahé and reared on “*Tabebnia* (sic) *pallida* (Calice du Pape)”, which he states to be a member of the Papilionaceae whereas *Tabebuia pallida* (“kalis-di-pap” in Creole) actually belongs to the family Bignoniaceae.

The adult has been seen hovering over *Crinum asiaticum* (Amaryllidaceae) in bloom at Fiennes Esplanade in Victoria and feeding from *Hippobroma longiflora* (Campanulaceae) flowers in various localities on Mahé (pers. obs.).

***Batocnema cocquerelii aldabrensis* AURIVILLIUS, 1905**

[E = Aldabra harlequin hawkmoth; F = sphinx arlequin d’Aldabra]

G: not recorded from the inner, granitic, islands

C: **Aldabra** - one single specimen known, collected in 1895 by Alfred VOELTZKOW and described as follows by AURIVILLIUS (1909) [translated from the original German]: “The specimen before me is very similar in coloration to the main form from Madagascar as described by ROTHSCILD and JORDAN. If, however, BOISDUVAL’s figure is correct, then its markings differ not insignificantly from those of the Madagascar form. The front wings have a fifth costal spot in the centre of the last third of the anterior margin, and the dark marginal band of the hind wings ends at vein 7 and therefore does not reach the anterior margin. If this form is different from the Madagascar form, it may be called “var. *aldabrensis*”.” The type is in Berlin (Ian KITCHING, pers. comm., 2004).

IO: The nominal subspecies, *B. c. cocquerelii* (BOISDUVAL, 1875) occurs in Madagascar and *B. c. comorana* Rotschild & Jordan, 1903 in the Comoros (GRIVEAUD 1959).

W: not recorded outside the Western Indian Ocean

Host plants: There is no information available on the larval host plant(s) of this species. In southern Africa the larva of *B. africana* (DISTANT, 1899) feeds on *Sclerocarya caffra* and *Mangifera indica*, both members of the Anacardiaceae (PINHEY 1962). The only member of this family that is native to Aldabra is *Poupartia gummifera* (FRIEDMANN 1994). According to WALTHER (1994), in Madagascar *B. cocquerelii* is a pollinator of *Cryptostegia madagascariensis* (Asclepiadaceae). Four species of the Asclepiadaceae are native to Aldabra: *Secamone pachystigma*, *Tylophora coriacea*, *Sarcostemma viminale* and *Pleurostelma cernnum* (FRIEDMANN 1994).

***Cephonodes hylas virescens* (WALLEGREN, 1865)**

[E = African bee hawkmoth; F = sphinx bourdon africain]

G: **Mahé** (JOANNIS 1894; HOLLAND 1895; HAMPSON 1908; FLETCHER 1910; FRYER 1912; LEGRAND 1966; pers. obs.: adults flying during daytime and at light), **Conception** (pers. obs.: adult flying during daytime), **Silhouette** (FRYER 1912; LEGRAND 1966; GERLACH 1998 & 2000; Justin GERLACH, pers. comm. 2004: sightings on 4th July 1997 & 9th August 2002; pers. obs.: adults flying during daytime), **Marianne** (HILL *et al* 2002: adult flying

during daytime in October 1999)

C: **Coëtivy** (FLETCHER 1910; LEGRAND 1966), **Poivre** (FLETCHER 1910), **D'Arros** (Fletcher 1910; pers. obs.: larvae on *Guettarda speciosa*, 16th June 2002; Justin GERLACH pers. comm., 2004: sighting on 21st June 2003), **Desroches** (LEGRAND 1966), **Alphonse** (Justin GERLACH, undated; quotes F. Payet as reporting having observed this species; pers. obs.: larvae on *Guettarda speciosa* on east coast, 22nd August 2004), **Aldabra** (FRYER 1912; LEGRAND 1966; 2 specimens in Aldabra insect collection, both labelled “Ex CClara (or EClara?), March 1978”), **Assomption** (Fryer 1912), **Cosmoledo (Menai)** (LEGRAND 1966)

IO: Madagascar, Mayotte (FLETCHER 1910), Glorieuses (E.S. BROWN, unpublished diary - see under host plants below; PAULIAN 1989)

W: Afro-tropical region

Host plants: *Guettarda speciosa* (Rubiaceae); *Canthium bibracteatum* (Rubiaceae) (GERLACH 1998); on Aldabra LEGRAND (1966) found larvae on an unidentified “bois café”, possibly *Polysphaeria multiflora* (Rubiaceae), which FOSBERG & RENVOIZE (1980)) call “café”, mentioning the use of its fruit as a substitute for real coffee (*Coffea* spp.; Rubiaceae). “*C. hylas*” (subspecies not specified) is reported to be a “minor pest” of *Coffea* in Africa, Asia and Australia (HILL 1975). SCOTT, the entomologist on the second Percy Sladen Trust Expedition to the Indian Ocean, wrote in his diary (unpublished) for August 16th 1908: “[Edouard] DAUBAN [owner of Silhouette] took net and caught large humming-bird hawk moths [sic] (clear-winged) hovering round papaya [=papaya, *Carica papaya*; Caricaceae] flowers at back of house [at La Passe on Silhouette].” FLETCHER (1910) found the adults to be especially common on Coëtivy, in September 1905, around the flowers of “bois balais” (*Erythroxydon* sp., presumably *E. platycladum*, Erythroxylaceae). LEGRAND (1966) noted that they were also common on Coëtivy in February around the flowers of *Guettarda speciosa* (Rubiaceae). On Silhouette, GERLACH (1998) observed adult moths feeding on the flowers of *Catharanthus roseus* (Apocynaceae) and *Asystasia* sp. (Acanthaceae), as well as on flowers of *Intsia bijuga* (Caesalpiniaceae) (Justin GERLACH, pers. comm., 2004). E.S. BROWN was presumably referring to this species when he wrote in his diary (unpublished) while visiting the Glorieuses islands on November 22nd 1951: “Caught a hawkmoth at flowers of bois cassant [=”bwa kasan bordmer”, *Guettarda speciosa*] (looks like a large mason wasp on wing).”

This dayflying species is often observed darting over scrubby vegetation in areas of “glasi” (exposed granite) (pers. obs.).

Cephonodes tamsi GRIVEAUD 1960

[E = Seychelles bee hawkmoth; F = sphinx bourdon des Seychelles]

G: **Mahé** (GRIVEAUD 1960; pers. obs. of specimen caught by Frey mentioned below), **Silhouette** (Gerlach 1998) & **Praslin** (KITCHING & CADIOU 2000). A male of this endemic species, reared by Hans Paul THOMASSET from a caterpillar collected on Mahé in October 1911, remained undescribed until GRIVEAUD (1960) described and named it – this holotype is in the Cambridge University Museum, U.K. (LEGRAND 1966; KITCHING & CADIOU 2000). In August 1952 E.S. BROWN collected a specimen on Praslin, but this

one, in the NHM, remained unnoticed until KITCHING & CADIOU (2000) drew attention to it. Interestingly, the entry for 26th February 1953 in BROWN's diary (unpublished) reads: "Went to Ste Anne [island] ... Saw bee hawkmoth (like that caught on Praslin)." Meanwhile, on 16th July 1997 GERLACH (1998) re-discovered the species feeding on *Lantana camara* flowers at La Passe on Silhouette. The first specimen was feeding at 17:40; subsequent observations were made between 17:00 and 17:30 and between 11:30 and 12:00. On 3rd November 2003 Felix FREY caught a specimen at light at Anse Nord-Est on Mahé (pers. obs.).

C: not recorded from the outer, coralline, islands

Host plant: *Canthium bibracteatum* (Rubiaceae) (GRIVEAUD 1960).

Daphnis nerii (Linné, 1758)

[E = oleander hawkmoth; F = sphinx du laurier rose]

G: **Mahé** (JOANNIS 1894; HAMPSON 1908; FLETCHER 1910; FRYER 1912; LEGRAND 1966; pers. obs: caterpillars on *Tabernaemontana divaricata*, incl. at Fiennes Esplanade in Victoria, and adults at light in residential areas up to 300m), **Silhouette** (Justin GERLACH, pers. comm. 2004: specimen sighted on 8th January 2001), **Aride** (BOWLER *et al* 1999).

C: not recorded from the outer, coralline, islands

IO: Madagascar, Comoros, Mauritius, Réunion, Sri Lanka

W: Afro-tropical, Palaearctic and Oriental regions; became established in Hawaii in 1974 (BEARDSLEY 1979).

Host plants: *Tabernaemontana divaricata* (Apocynaceae); *Nerium oleander* (Apocynaceae) (LEGRAND 1966).

Hippotion aurora ROTHSCHILD & JORDAN, 1903

[no common names known]

Further work is needed to verify the validity of "*H. aurora delicata*" ROTHSCHILD & JORDAN, 1915, (corrected to "*H. a. delicatum*" by CARCASSON (1976)) described from a single "much injured" male that FLETCHER collected on Farquhar in October 1905. FLETCHER (1910) wrote of a specimen of *H. aurora* from Coëtivy: "This appears to be a dwarfed and faintly-marked form of *H. aurora*." Further on he added: "The examples from Coëtivy and Farquhar are both lighter in ground-colour than the typical form and perhaps represent local races." A question mark hangs over this, however, because both specimens were obtained from captive larvae.

G: not recorded from the inner, granitic, islands

C: **Coëtivy** (FLETCHER 1910), **Alphonse** (Justin GERLACH undated, quotes F. PAYET as reporting having seen this species), **Rémire** (FLETCHER 1910: "remains of large numbers of empty pupa-cases, apparently belonging to this species, were found under stones"), **Assomption** (FRYER 1912), **Farquhar** (FLETCHER 1910).

IO: Madagascar; Glorieuses: ROTHSCHILD & JORDAN (1915) described the subspecies *H. aurora gloriosana* based on two males from there (corrected to "*H. a. gloriosanum*" by CARCASSON (1976))

W: not recorded outside the western Indian Ocean

Host plants: FLETCHER (1910) found the larvae on *Guettarda speciosa* (Rubiaceae)

on Coëtivy, and on *Pisonia* “*calpidia*” (presumably *P. grandis*) (Nyctaginaceae) on Farquhar.

***Hippotion celerio* (LINNÉ, 1758)**

[E = silver-striped hawkmoth; F = sphinx phoénix]

G: not recorded from the inner, granitic, islands

C: **Coëtivy** (FLETCHER 1910; LEGRAND 1966), **Desroches** (LEGRAND 1966), **Alphonse** (pers. obs.: one hovering over a bouquet of flowers in the hotel conference room on 27th July 2003; a specimen with deformed wings found crawling on the ground on the eastern side of the runway at 6.40 p.m. on 21st August 2004), **Cosmoledo (Menai)** (LEGRAND 1966)

IO: Madagascar, Glorieuses (PAULIAN 1989), Comoros (where it is said to be the most abundant Sphingid (DALL’ASTA & TURLIN 2004)), Mauritius, Réunion, Socotra & Abdel-Kuri (Yemen) (FLETCHER 1910)

W: Afrotropical, Oriental and Australian; migrates into the Palaearctic (PITTAWAY 2004)

Host plants: There are no records of host plants for *H. celerio* in Seychelles. PICKER *et al* (2002) include “grape vines [*Vitis vinifera*], *Arum*, *Impatiens*, carrot tops [*Daucus carota*]...” in their list for South Africa. According to PITTAWAY & KITCHING (2004), “for breeding colonies to become established, the presence of cultivated or wild Vitaceae [the grapevine family] is essential”. None of the above plants is known to grow in the outer, coralline, islands where this hawkmoth has been found. Of the larval hostplants mentioned by MOULDS (1981) for Australia (“24 species in 9 families”), *Boerhavia diffusa* (Nyctaginaceae) has been found growing on “Ile aux Vaches” (presumably Bird Island) only (FRIEDMANN 1994), while *Ipomoea batatas* (Convolvulaceae) would not grow wild and would be cultivated only occasionally in the outer islands. Other *Boerhavia* species (*B. africana*, *B. crispifolia*, and *B. repens*) do occur in the outer islands. MOULDS (1984) adds “frangipani”, *Plumeria rubra* (Apocynaceae), a cultivated ornamental. *H. celerio* has been recorded as a pest of *Colocasia esculentum* (Araceae) in New Guinea and the islands of the Pacific as well as cotton (*Gossypium hirsutum*; Malvaceae) in East Africa (LAMB 1974).

KITCHING & CADIOU (2000) have pointed out that the hawkmoth from Seychelles that D’ABRERA (1987) illustrated as *Hippotion isis* ROTHSCILD & JORDAN (1903) is in fact “a small, pale [*Hippotion*] *celerio* that had been bred by Fletcher (1910) and later misidentified in the BMNH [Natural History Museum, London] collection”.

***Hippotion eson* (CRAMER, 1779)**

[E = common striped hawkmoth; F = ?]

G: **Mahé** (JOANNIS 1894; FLETCHER 1910: including one at light in Port Victoria; LEGRAND 1966: Beau Vallon; pers. obs.: larvae on food plants up to 600m, adults at light at Marie Laure Estate, at Hermitage & Ma Joséphine), **Silhouette** (FRYER 1912; FLOATER 1993; pers. obs.: larvae on food plants)

C: not recorded from the outer, coralline, islands

IO: Madagascar, Comoros, Mauritius, Réunion

W: Afrotropical

Host plants: The larva of this widespread Afrotropical species has a predilection for endemic plants - *Protarum sechellarum* (Araceae) (SCOTT, 1933; pers. obs.), *Dillenia ferruginea* (FLOATER, 1993; pers. obs.: only the young, fleshy leaves) *Begonia seychellensis* (FLOATER 1993; pers. obs.) and *Impatiens gordonii* (MATYOT 1996; WISE 1998; Denis MATATIKEN, pers. comm., 2001). It is the only hawkmoth caterpillar encountered regularly in the damp high altitude forests, up to at least 500m, and its range extends down to the lowermost *D. ferruginea*, e.g. at 90m at Marie Laure (=Mount Simpson) Estate in Bel Ombre district. On Silhouette the moth has been observed hovering over the flowers of *Catharanthus roseus* (Apocynaceae) at dusk (Justin GERLACH, pers. comm., 2004).

***Hippotion geryon* (BOISDUVAL, 1875)**

[no common names known]

G: not recorded from the inner, granitic, islands

C: **Aldabra (Picard)**: The first known specimen from Aldabra (precise locality not recorded) is a male collected by VOELTZKOW in 1895 and mentioned by AURIVILLIUS (1909); there were no further records until FRITH (1979): 48 specimens were caught over a 12-month period (September 1971-August 1972) by means of two Heath light traps set up for 2-10 nights per month in two localities on Picard Island; a Rothamsted light trap in a third locality did not catch any. The Aldabra insect collection contains two specimens, one labelled, confusingly, "*Hippotion osiris*, found [in/near?] boat shed, 25th March 1976, West Island [=Picard], M.W. [probably Marilyn WALKER]", the other labelled "Heath trap, Picard, 6th February 1978"; both specimens beside a third label: "*Hippotion geryon*".

IO: Madagascar

W: Not recorded outside the western Indian Ocean.

Host plants: Unknown.

***Hippotion osiris* (DALMAN, 1823)**

[E = greater silver-striped hawkmoth; F = ?]

G: **Mahé** (JOANNIS 1894; HAMPSON 1908; FLETCHER 1910; FRYER 1912; LEGRAND 1966: at Beau Vallon; pers.obs.: larvae on all known food plants up to 350m), **Praslin** (FLETCHER 1910), **Silhouette** (Justin GERLACH, pers. comm. 2004: reared from *Morinda citrifolia* on 1st December 2003).

C: not recorded from the outer, coralline, islands

IO: Madagascar

W: Afrotropical region; migrates to North Africa and southern Europe (PITTAWAY 2004)

Host plants: *Vitis vinifera* (Vitaceae); *Pentas lanceolata* (Rubiaceae); *Morinda citrifolia* (Rubiaceae), *Impatiens balsamina* & *I. wallerana* (Balsaminaceae); *Caladium* sp. (Araceae).

***Macroglossum alluaudi* De JOANNIS, 1893**

G: **Mahé** (JOANNIS 1893 & 1894), **Silhouette** (GERLACH 2000: La Passe; Justin GERLACH, pers. comm. 2004: sighting at Jardin Marron in December 2003). Until the re-discovery

of this endemic species on Silhouette by Justin GERLACH on 10th July 2000 (GERLACH 2000), only three specimens dating from the end of the 19th century were known: the type, a female collected by Charles ALLUAUD on Mahé some time between 17th March and 16th May 1892 and now in the Muséum National d'Histoire Naturelle in Paris (JOANNIS 1893); another (female?) in the possession of the German Lepidopterist Otto STAUDINGER (1830-1900) who reported that it had been caught in Seychelles on “August 31st” (1892?) (JOANNIS 1893), this being presumably the specimen in the Berlin Museum referred to by LEGRAND (1966); and a female reared from a larva collected on Mahé and sent to JOANNIS by Father PHILIBERT (current whereabouts of this specimen unknown).

C: not recorded from the outer, coralline, islands

Host plants: *Morinda citrifolia* (JOANNIS 1894) (“bois tortue” = “bwa torti”, Rubiaceae and not Meliaceae). Other species of *Macroglossum* elsewhere are known to feed on *Morinda* spp., including *M. citrifolia* (MOULDS 1998). At La Passe on Silhouette the adult moth has been observed feeding on flowers of *Lantana camara* (GERLACH 2000).

Nephele leighi JOICEY & TALBOT, 1921

G: **Mahé** (JOICEY & TALBOT 1921; LEGRAND 1966; ANONYMOUS 1969), **Silhouette** (FRYER, 1912). The first known specimen of this endemic species, a male caught on Silhouette in 1908 during the second Percy Sladen Trust Expedition to the Indian Ocean, was mentioned by FRYER (1912), who mistook it for *N. hespera* (FABRICIUS, 1775), an Oriental and Australian species (PITTAWAY & KITCHING 2004; MOULDS 1996). Still mislabelled, it is at present in the Cambridge Museum of Natural History in the U.K. (Martin HONEY & Justin GERLACH, pers. comm. 2004). Unfortunately, the label gives no indication as to the precise locality where it was collected and who the collector was – John FRYER himself, Hugh SCOTT or John Stanley GARDINER (all three expedition members were on Silhouette in August 1908) or one of the island residents who helped Scott with insect-collecting. The entry in SCOTT’s unpublished diary for August 27th 1908, when he was staying in a house at Mare aux Cochons on Silhouette, includes the following: “Caught brown Sphingid moth which flew to light.” His entry for September 25th, in the same locality, includes the line: “Hawk-moth flew to lamp in house, caught.” One of these entries may be a reference to the specimen in question. The description of *N. leighi* was based on a female, caught on Mahé in 1913 by the South African insect collector George F. LEIGH and now in the Natural History Museum in London. A third specimen, also a female, was caught in May 1960, at Mont Fleuri on Mahé, by the Rev. Brother Camille QUEVILLON of the Seychelles College and given to LEGRAND during his second collecting trip to Seychelles (LEGRAND 1966); it is now in the Muséum National d'Histoire Naturelle in Paris. A fourth specimen, a second male, was caught at Sans Souci on Mahé, apparently at the beginning of 1969, by “Mrs Ian FROST” (ANONYMOUS 1969); unfortunately, it is not known what happened to it. The species has not been found again since then.

C: not recorded from the outer, coralline, islands

Host plants: HUWER & McFADYEN (1999) have discussed the possible evolution of host plant specialisation in the genus *Nephele*. Published information on larval food plants of members is summarised in Table 1. The *Nephele*-*Carissa* relationship extends to

pollination in some cases: in India, *N. didmya* (FABRICIUS, 1775) (= *N. hespera*) is said to be one of the pollinators of *C. spinarum* (BHATNAGAR 1986).

***Temnora fumosa peckoveri* (BUTLER, 1877)**

[E = smoky Temnora; F = ?]

G: **Mahé** (JOANNIS 1894; FRYER 1912; LEGRAND 1966; pers. obs.: at light at Marie-Laure in Bel Ombre district (dates not recorded), at Hermitage in Mont Fleuri district in February 1998, and at L'Harmonie, La Misère on 29th August 1999; caterpillar found on the ground at Anse Nord-Est on 2nd March 2005), **Silhouette** (Fryer 1912; Justin GERLACH, pers. comm. 2004)

C: **Denis** (Justin GERLACH, pers. comm. 2004: "not uncommon" in 2003; reported rearing a caterpillar on *Morinda citrifolia*)

IO: Madagascar, Comoros

W: The nominal subspecies occurs in the Afrotropical region.

Host plants: The larval food plant of this species was first discovered by Justin GERLACH, who collected a caterpillar on *Morinda citrifolia* (Rubiaceae) on Denis island in 2003 and successfully reared it on leaves of this plant (pers. comm. 2004). The caterpillar mentioned above that was found at Anse Nord-Est was thrashing about on the ground under a mature *M. citrifolia* (Rubiaceae) while yellow crazy ants (*Anoplolepis gracilipes* (SMITH, 1857); Formicidae) swarmed all over it (pers. obs.): it was rescued, pupated on 4th March after refusing to feed on either *M. citrifolia* or *Guettarda speciosa*, and a male moth, with truncate anal tuft, emerged 12 days later. There is confusion regarding the host plant of the nominal subspecies in South Africa: according to PINHEY (1962) *T. fumosa* (*fumosa*) is "said to feed on *Camelina*" (*C. sativa*, Cruciferae) but in PINHEY (1975) this changed to "feeds on *Commelina*" (Commelinaceae)!

Ecological importance as pollinators

Hawkmoths are the specialised pollinators, primary pollinators or secondary pollinators of many plants. These display the suite of floral characters that are associated with the pollination strategy or "syndrome" termed sphingophily, i.e. adaptations for pollination by Sphingidae (Table 2).

This has implications for the pollination of many plants that are part of the native biodiversity of Seychelles, as well as numerous plants of agricultural and horticultural importance at a time of growing recognition "that honeybees (*Apis* spp.) cannot pollinate all crops and that a high diversity of pollinators is mandatory" and increasing concern in some parts of the world at "the demise of natural pollinator populations caused by pesticide application, habitat destruction, monocultures, etc." (WESTERKAMP & GOTTSBERGER 2000). Concern that "changes in the abundance and diversity (of pollinators) will influence the abundance and diversity of prevailing plant species" (EARDLEY, 2004) led to the creation by the Convention on Biological Diversity (Decision V/5, 2000) of the International Initiative for the Conservation and Sustainable Use of Pollinators, known as the International Pollinator Initiative (IPI) for short, under the auspices of the United Nations Food and Agriculture Organisation (FAO), with the African Pollinator Initiative (API) as a branch. KEARNS *et al* (1998) have pleaded for

ecologists to “redouble efforts to study basic aspects of plant-pollinator interactions if optimal management decisions are to be made for the conservation of these interactions in natural and agricultural ecosystems”. Sphingidae have to be included in such studies.

To feed on nectar from a flower, most species of hawkmoth remain on the wing, hovering over the flower and introducing their proboscis or “tongue” into the corolla tube or spur. The “fit” between the moth and the flower, in terms of nectar being available to the foraging moth, depends on the floral tube being short enough for the proboscis of the Sphingid to reach the nectar it contains; but to ensure that there is effective cross-pollination and not just “floral larceny” (the removal of nectar without provision of pollination service (IRWIN *et al* 2001)), two key criteria have to be met: (1) pollen must stick to the moth (usually the head, the base of the proboscis or the antennae); and (2) pollen gathered from one flower must be transferred to the stigma of another. While a short-tongued moth cannot sip nectar from a long-tubed flower, a long-tongued moth can exploit flowers with different lengths of tube but it may not collect pollen from one short-tubed flower and transfer it efficiently to another because it does not have to push its head into the flower. DARWIN’s suggestions (1862) regarding the run-away coevolution of flowers with deep tubes and pollinators with long tongues have been supported by more recent studies (NILSSON 1988; ALEXANDERSSON & JOHNSON 2002). Published data on the proboscis lengths of some Sphingids occurring in Seychelles, but based on specimens collected elsewhere, is summarised in Table 3.

There is very little published information on the pollination strategies of both introduced and native plants in Seychelles, the most detailed work being probably that of WOODDELL (1979), but that did not touch upon sphingophily apart from quoting a suggestion that “some hawkmoths are associated especially with *Convolvulus* species”. In Queensland, Australia, one study (GARRETT 1995) indicated that the only significant method of pollination of the important tropical fruit crop papaya (*Carica papaya*, Caricaceae), much grown in Seychelles, was by hawkmoths: seven species, including *Hippotion celerio*, were proven pollinators and four others, including *Cephonodes hylas cunninghami* (WALKER, 1856) were suspected pollinators. WESTERKAMP & GOTTSBERGER (2000) also state that the pollinators of papaya are Sphingidae, although they mention reports of parthenocarpy (fruit development without pollination) in *C. papaya*. They go on to recommend that “good conditions for the hawkmoth pollinators must be ensured for successful pollination”. Other plant species of agricultural or horticultural importance in Seychelles that are reported to be pollinated by Sphingidae elsewhere include the bottle gourd *Lagenaria siceraria* (family Cucurbitaceae) (MORIMOTO *et al* 2004) and the ornamental *Mirabilis jalapa* (family Nyctaginaceae) (MÜLLER 1883).

It is of greater relevance to biodiversity conservation efforts to consider pollination by hawkmoths among the endemic and other native plants of Seychelles. Candidate species, with at least some of the characters attributed to sphingophily, are listed in Table 4. Further work may show that some of these are pollinated by other moths, such as Noctuidae.

The case of the *Angraecum* orchids (Orchidaceae) recalls what has been termed “Darwin’s Madagascan hawk moth prediction” (KRITSKY 1991): DARWIN (1862)

suggested that there must be Lepidoptera in Madagascar with probosces long enough to reach the bottom of the spurs of *Angraecum sesquipedale*, 29cm long; then WALLACE (1867 & 1871) pointed out that an African Sphingid, *Xanthopan morganii*, had a proboscis that came close to the required length, after which the subspecies *X. morganii praedicta* ROTHSCILD & JORDAN, 1903 with a proboscis 25cm long was actually discovered in Madagascar. *Angraecum eburneum* subsp. *brongniartianum*, sometimes referred to as *A. eburneum* subsp. *superbum* (ROBERTSON 1989), the “national flower” of Seychelles, has a spur that may be up to 15cm long (ROBERTSON 1989; pers. obs.). As for *Impatiens gordonii* (Balsaminaceae), the possibility of sphingophily is supported by the fact that some *Impatiens* species elsewhere are known to be pollinated by hawkmoths: a study of four *Impatiens* species in Sumatra, Indonesia has shown that spur morphology essentially determines nectar accessibility, with *I. platypetala* (pink flowers, long filiform spurs) being pollinated by the crepuscular hawkmoth *Macroglossum corythus* (WALKER, 1856) (KATO *et al* 1991). Diurnal hawkmoths are among the secondary pollinators of *I. reptans* in China (TIAN *et al* 2004). The genus *Carissa* (family Apocynaceae) has an interesting association with Sphingidae: not only are the leaves of several African, Asian and Australian species fed upon by the larvae of various species of *Nephele* (discussed under *Nephele leighi* above), but also the flowers of *C. spinarum* in India are reported to be pollinated by *Nephele didyma* (FABRICIUS, 1775) (= *N. hespera* (FABRICIUS, 1775)) (BHATNAGAR 1986) and those of *Carissa grandiflora* in South Africa are said to be pollinated by unspecified hawkmoths (MARLOTH 1932). It is possible that *C. edulis* var. *sechellensis* is also pollinated by Sphingidae. Regarding *Crinum augustum*, hawkmoth-pollination is known in members of the genus *Crinum* outside Seychelles, e.g. *C. variable* (MANNING & SNIJMAN 2002).

Finally, mention must be made of naturalised exotic plants that are sphingophilous. One of them is the poisonous weed *Hippobroma longiflora* (Campanulaceae), which has been observed being visited by *Agrius convolvuli* (pers. obs.) on Mahé. Interestingly, the nectar of *H. longiflora* is believed to have toxic or deterrent properties (ADLER 2001). The bee hawkmoths *Cephonodes tamsi* and *C. hylas virescens* and the hummingbird hawkmoth *Macroglossum alluaudi* have been observed feeding on the flowers of the introduced *Lantana camara* (Verbenaceae), with *C. hylas virescens* feeding on the flowers of two other exotic species, *Catharanthus roseus* (Apocynaceae) and *Asystasia* sp. (Acanthaceae) as well (GERLACH 1998 & 2000).

Ecological importance as part of food chains

As plant feeders, at both larval and adult stages, the Sphingidae are primary consumers that are the prey of secondary consumers, including as hosts of parasitoids and parasites (JANZEN & GAULD 1997). Observations have been collected over the years on the food plants in Seychelles of the larval stages of the common, widespread species (discussed under the individual species above), but information is lacking on the plants consumed by the caterpillars of endemic species. One widespread Sphingid is known, at the larval stage, to feed on endemic plants: this is *Hippotion eson*, which has been observed feeding on not only *Protarum sechellarum* (Araceae) (SCOTT 1933; pers. obs.), *Dillenia ferruginea* (Dilleniaceae) and *Begonia sechellensis* (Begoniaceae) (FLOATER

1993; pers. obs.) but also on *Impatiens gordonii* (Balsaminaceae), (MATYOT 1996; WISE 1998; Denis MATATIKEN, pers. comm. 2001), the last-mentioned plant being known from only two sites on Mahé and one on Silhouette and considered to be endangered in terms of the IUCN's Red List categories (GERLACH 1997); individual plants of *P. sechellarum* and *I. gordonii* are occasionally almost completely defoliated (pers. obs.). The subject of host plants is discussed further in connection with conservation issues. There is also inadequate information on the range of flowers visited by adults of both endemic and non-endemic hawkmoths; as previously mentioned, two recently rediscovered endemic species, *Cephonodes tamsi* and *Macroglossum alluaudi*, are known to feed on nectar from the naturalised exotic *Lantana camara* (Verbenaceae) (GERLACH 1998 & 2000).

The caterpillars of Sphingidae use a number of protective and defence strategies against potential predators, several occurring simultaneously in many species: cryptic coloration; countershading to create an illusion of flatness; death feigning or thanatosis; "snake mimicry" in which the eyespots come into play, sometimes combined with "warning sounds" that have been compared to the hiss of a snake in the case of *Acherontia atropos* and *Hippotion osiris* (pers. obs.); regurgitation of fore-gut contents; and unpalatability resulting from the ingestion and sequestration of defensive phytochemicals, e.g. *Acherontia atropos* sequesters the tropane alkaloid calystegine, neurotoxic to vertebrates, from plants of the family Solanaceae (NASH *et al* 1993; NISHIDA 2002). There does not seem to be any account of a bird or reptile feeding on Sphingid larvae in Seychelles. A still moving *Cephonodes hylas virescens* caterpillar with the anterior portion of the body missing was found on *Guettarda speciosa* on Alphonse island (pers. obs. on 22nd August 2004); this was obviously the result of an attack by a predator, possibly a bird. A late but not final instar *Acherontia atropos* caterpillar was once observed to have been caught by the spider *Rhytimna valida* (BLACKWALL, 1877) on a *Solanum melongena* plant at La Rosière on Mahé (pers. obs. on 5th September 1997). The spider, a gecko-eating species, was holding the caterpillar in its jaws and appeared to be sucking its body juices. The yellow paper wasp *Polistes olivaceus* (DEGEER, 1773) preys on young caterpillars of *Hippotion osiris* (pers. obs. at La Rosière on Mahé on 3rd September 2004). No detailed survey of the parasites that target Sphingid larvae in Seychelles has yet been carried out, but the larvae of *Acherontia atropos*, *Agrius convolvuli* and *Deilephila nerii* on Mahé are frequently parasitised by numbers of the Ceratopogonid midge *Forcipomyia lasionata* (KIEFFER, 1911) (pers. obs.); presumably it is the same species that has been observed on the larvae of *Hippotion eson* on Silhouette (Justin GERLACH, pers. comm.). This midge is not a Sphingid specialist: it is frequently found on stick insects (*Carausius* spp., Phasmatodea) as well.

Adult hawkmoths, too, employ a range of strategies to avoid, confuse, startle or ward off potential predators: "swing-hovering" (WASSERTHAL 1993), cryptic coloration, including disruptive coloration; flash coloration, e.g. the bright pink on the hind wings of most *Hippotion* species; and unpalatability combined with warning coloration (aposematism), e.g. the bright yellow hind wings of *Acherontia atropos*. Still, the wings and body parts of the adults of the last-mentioned species as well as those of *Agrius convolvuli* and *Cephonodes hylas virescens* have been found on several occasions under the roosting site of a Seychelles kestrel (*Falco araea*, Accipitridae) at the SBC TV

station at Hermitage on Mahé (pers. obs.). This was an artificial situation in the sense that the kestrel was roosting under a verandah where at night electric lighting “attracted” hawkmoths and other insects. It is known that birds circumvent the distastefulness or toxicity of Lepidopteran prey either behaviourally, by avoiding the cuticle rich in sequestered defensive chemicals, or physiologically, by developing insensitivity (FINK & BROWER 1981).

Conservation issues

There is a basic interdependence relationship between Sphingidae and Angiosperms (flowering plants) in that the moths depend on the plants for food (leaves for the larval stages and nectar for the adults) while a large number of plants depend on the adult moths to pollinate their flowers. Changes in the numbers and diversity of one would impact on the numbers and diversity of the other. There are a number of threats resulting from human activity to the Sphingidae of Seychelles:

1. Fragmentation and elimination of natural habitats as a result of land clearing, exploitation of forestry resources, forest fires, etc.: This has been documented and commented upon by a number of authors (e.g. FRIEDMANN 1994; GERLACH 1997). As the populations of the plants on which a specialised pollinator depends for nectar drop towards a critical minimum threshold, and the frequency of pollinator-flower encounter can no longer meet the nutritional requirements of the pollinator, then the pollinator faces the threat of extinction. A similar situation arises as the availability of larval food plants is reduced and eventually disrupted. The apparent rarity of the three endemic Sphingids of the granitic islands, *Macroglossum alluaudi*, *Cephonodes tamsi* and *Nephele leighi*, may be due, in part at least, to this type of anthropogenic impact. In turn, the remaining populations of the plants that depend on the moths for pollination would not be reproductively viable if there are no alternative pollinators. Further study is required to verify if any examples of this extreme scenario exist in Seychelles.

2. Introduction of alien plants: This can act in a number of ways to alter the numbers and composition of the Sphingid fauna. Firstly and most obviously, invasive exotic plants can compete with and displace the native plants that some Sphingidae may depend on for nectar and as larval hosts. Secondly and less apparently, invasive aliens can integrate into native flower-pollinator visitation webs (MEMMOTT & WASER 2002), leading to competitive interactions such as flowering invaders acting as Sphingid (pollinator) attractors that cause a diminished pollination service to native plants (SPENCE *et al* 2003). Support for this is provided by evidence that learning (associative conditioning) from previous odour experience strongly influences the odour preference and floral choice of foraging and possibly even egg-laying moths (CUNNINGHAM *et al* 2004), i.e. if the most abundant rewarding host that a foraging moth is exposed to initially is an alien (assuming that the moth is not a floral specialist) it will be most attracted after that to the same host, and rarer potential native hosts will be visited less often.

On the other hand, the integration of alien plants into native pollination

networks may be beneficial (MEMMOTT & WASER 2002): the aliens may be alternatives or substitutes for native hosts that are rare or extinct or that may not be flowering, e.g. the two endemic species *Cephonodes tamsi* and *Macroglossum alluaudi* have been observed foraging on only the flowers of the notorious tropical weed *Lantana camara* (Verbenaceae) on Silhouette (GERLACH 1998 & 2000). A number of moths, including *Macroglossum hirundo* (BOISDUVAL, 1832), feed on *Lantana camara* flowers on Moorea (Society Islands, French Polynesia) in the Pacific (Anthony DARROUZET-NARDI, pers. comm., 2004). This situation would be of greatest benefit to generalist Sphingids though, and may partly explain the relative abundance of widespread, non-endemic, species.

3. Introduction of alien predators, parasitoids and parasites: Introduced predators with omnivorous and opportunistic feeding habits must have impacted negatively on the populations of Sphingids in Seychelles, although quantitative data is wanting to substantiate this. Rats (*Rattus* spp.), mice (*Mus musculus*) (Rodentia: Muridae) and the Indian mynah (*Acridotheres tristis*) (Passeriformes: Sturnidae) may feed on the egg, larval or pupal stages of at least some species – a rat (*Rattus* sp.) perched on a roof beam was once observed lunging at an *Agrius convolvuli* that was fluttering near the ceiling inside a house (pers. obs.). The tenrec *Centetes ecaudatus* (Insectivora: Tenrecidae) could presumably feed on the pupae of species that pupate in leaf litter or just below the ground. The yellow crazy ant *Anoplolepis gracilipes* is known to reduce the populations of many invertebrates in the territories that it colonises (HAINES & HAINES 1978a, b); mention has already been made of this alien invasive species attacking the larva of *Temnora fumosa peckoveri*. Perhaps even more insidious would be the impact of introduced parasitoids and parasites which may not be host specific and therefore may attack non-target species including endemic Sphingids. WATERHOUSE (1998) has listed the Diptera, Hymenoptera and fungi that are known to be “natural enemies” of *Agrius convolvuli* in various parts of the world. It is known that the parasitoid *Diadegma semiclausum* (HELLEN, 1949) (Hymenoptera: Ichneumonidae) and “a couple of other species also” were released in Seychelles in the 1970s as potential biological control agents to fight the diamondback moth (*Plutella xylostella* Schrank, 1802) (Lepidoptera: Plutellidae), a pest of cabbage and other Cruciferae (M. SHEPARD, pers. comm., 2001).

4. Artificial lighting: FRANK (1988) has summarised much of what is known about the ecological impact of artificial night-time lighting, including its adverse effects, on moth populations, although he stressed the lack of quantitative studies. This includes flight-to-light behaviour that interferes with other activities such as feeding, mating and oviposition; moths getting trapped inside buildings and lamp housings; and clumping of moths near lamps so that predation by birds and other insectivorous animals is increased, as are the chances that humans will find and kill the moths. In this context it is interesting to recall that ESTRIDGE (1885), in the very first account of Sphingidae in Seychelles, noted how lights influence the behaviour of hawkmoths! Reduced light pollution, including the use of shields to block stray light or the use of low-pressure sodium lamps to replace other forms of lighting, as has been recommended to prevent turtle hatchlings from being disorientated (Jeanne MORTIMER, pers. comm.) may have to

be considered in specific areas with important populations of endemic Sphingidae and other nocturnal insects.

5. Deliberate killing by humans: The hawkmoths and other large moths are called “lay” in Creole (from the Malagasy “ley” (D’OFFAY & LIONNET 1982)). They are well-known to the Seychellois who hold them in awe because of two popular beliefs: one is that hawkmoth caterpillars can squirt a substance that can damage eyesight into the eyes of humans; and the other, mentioned by FLETCHER (1910) in connection with *Acherontia atropos*, is that the “dust” from the wings of adult hawkmoths can cause conjunctivitis and even damage eyesight. As a result, caterpillars and, more commonly, adult moths are frequently killed on sight (pers. obs.). Part, at least, of these unfortunate beliefs is obviously of French origin because LOUSADA (1984), writing about *Acherontia atropos*, says: “It was believed in central France that the dust from their wings would blind you if it fell on your eyes”. It is possible that allergic reactions in particularly sensitive individuals to the setae found on some other groups of moths (Lepidopterism) or to the urticating hairs of non-Sphingid larvae (caterpillar dermatitis or erucism) may have contributed to these myths (NORRIS 2004).

Conclusion

Because of their status as potentially important pollinators of native plants, Sphingidae should be included in biodiversity monitoring programmes in Seychelles. It is necessary to scrutinise more closely the biology and ecology of the various species, with particular attention to be paid to their associations with larval host plants and flowering plants visited by foraging adult moths, as well as to the impact of vegetation structure on the distribution of species. The ecological requirements of the endemic species, in particular, need urgent attention so that appropriate conservation measures can be adopted.

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Table 1: Larval host plants recorded for *Nephele* species outside Seychelles

Species	Larval host plant	Source
<i>Nephele accentifera</i> (Palisot de BEAUVAIS, 1805) in Afrotropical region	<i>Ficus pertseri</i> & <i>F. mammosa</i> (Moraceae)	PINHEY (1962)
<i>Nephele argentifera</i> (WALKER, 1856) in southern and eastern Africa	<i>Carissa macrocarpa</i> (Apocynaceae)	KROON (1999)
<i>Nephele comma</i> HOPFFER, 1857 in Afrotropical region	<i>Carissa bispinosa</i> , <i>C. condylocarpon</i> & <i>C. macrocarpa</i> (Apocynaceae)	KROON (1999)
	<i>Diplorhynchus cardylocarpus</i> (Apocynaceae)	PINHEY (1962)
<i>Nephele densoi</i> (KEFERSTEIN, 1870) in Madagascar	<i>Cryptostegia grandiflora</i> (Asclepiadaceae)	HUWER & MCFADYEN (1999)
<i>N. hespera</i> (FABRICIUS, 1775) in India	Carissa carandas (Apocynaceae)	BELL & SCOTT (1937)
<i>Nephele subvaria</i> (WALKER, 1856) in Australia	<i>Carissa ovata</i> (Apocynaceae)	HERBISON-EVANS & COSSLEY (2005)
<i>Nephele vau</i> (WALKER, 1856) in Afrotropical region	<i>Carissa edulis</i> (Apocynaceae)	KROON (1999)

Table 2: Floral characters typical of sphingophilous plants (pollinators = Sphingidae) (Sources: HABER & FRANKIE 1989; KNUDSEN & TOLLSTEN 1993; MILLER 1997; MIYAKE *et al* 1998; GIBSON 2001; LEVIN *et al* 2001)

Colour	white (how this fits with scotopic colour vision in Sphingidae (KELBER <i>et al</i> 2002 & 2003) remains to be fully elucidated)
Form and structure	large and conspicuous, or small in a conspicuous group; long tubular corolla or spur containing nectar at the bottom (accessible to extended proboscis); no platform (hawkmoth hovers over flower and does not alight)
Fragrance (attractant)	strong “sweet” perfume produced by volatile aromatic alcohols and esters, especially monoterpenoids (e.g. linalool) and sesquiterpenoids
Nectar type	relatively low sugar concentration (c. 20%), therefore watery (for easy extraction), rich in sucrose (high energy supply for active flight)
Time of opening (anthesis) and emission of floral scent	evening and/or night (in the daytime for flowers pollinated by day-flying hawkmoths)

Table 3: Proboscis length in some Sphingids found in Seychelles

Species	Mean proboscis length (millimetres)	Source
<i>Acherontia atropos</i>	(i) 13.0	(i) MILLER 1997
<i>Agrius convolvuli</i>	(ii) "short, but very thick and hairy" (i) up to 130	(ii) CARCASSON 1976 (i) PITTAWAY & KITCHING 2004
	(ii) 102.9±6.7 (range: 85.0 – 135.0)	(ii) ALEXANDERSSON & JOHNSON 2002
	(iii) 110.0±19.7	(iii) JOHNSON <i>et al</i> 2002
<i>Batocnema spp.</i>	(iv) 90.9	(iv) MILLER 1997
	(i) "short, only reaching to base of abdomen"	(i) PINHEY 1962
	(ii) "short, just extending beyond base of abdomen"	(ii) CARCASSON 1976
	20.1	MILLER 1997
<i>"Cephonodes hylas" (subspecies not specified)</i>	42.0	JOHNSON <i>et al</i> 2002
<i>Daphnis nerii</i>	(i) 36.8±1.7 (range: 32.0 – 42.0)	(i) ALEXANDERSSON & JOHNSON 2002
<i>Hippotion celerio</i>	(ii) 39.3±1.4	(ii) JOHNSON <i>et al</i> 2002
	47.0	JOHNSON <i>et al</i> 2002
<i>Hippotion eson</i>		

Table 4: Some endemic and other native plants of Seychelles displaying sphingophilous features (floral features based on FOSBERG & RENVOIZE 1980; ROBERTSON 1989; FRIEDMANN 1994; WISE 1998; & pers. obs.)

Species	Family	Floral features associated with sphingophilily
<i>Angraecum eburneum</i>	Orchidaceae	White flowers with spur ≤150 mm long (subspecies <i>brongniartianum</i> in the granitics) or <70 mm long (different subspecies on Aldabra); strong scent
<i>Calanthe triplicata</i>	Orchidaceae	Flowers white with spur
<i>Cynorchis fastigiata</i>	Orchidaceae	> 20 mm long
<i>Impatiens gordonii</i>	Balsaminaceae	Flowers creamy white tinged with pink, with spur ≤25 mm long
<i>Ipomoea macrantha</i>	Convolvulaceae	White flowers with spur ≤80 mm long
<i>Ipomoea venosa</i>	Convolvulaceae	Flowers white with tubular corolla ≤80 mm long
<i>Glonnetia sericea</i>	Rubiaceae	Flowers white with tubular corolla ≤40 mm long
<i>Guettarda speciosa</i>	Rubiaceae	Flowers creamy pink but turning deeper pink and maroon, with corolla tube ≤70 mm long; strong scent
<i>Rothmannia amae</i>	Rubiaceae	Flowers white with corolla tube ≤30 mm long; strong scent
<i>Carissa edulis</i> var. <i>sechellensis</i>	Apocynaceae	Flowers white, usually speckled with magenta; tubular corolla ≤ 40 mm long; strong
<i>Cerbera manghas</i>	Apocynaceae	scent
<i>Tabernaemontana coffeoides</i>	Apocynaceae	White flowers with corolla tube <12 mm long
<i>Jasminum jupitense</i> subsp. <i>mauritanum</i>	Olacaceae	Flowers white with purple or yellow centre, and corolla tube ≤40 mm long; strong scent
<i>Psychotria capensis</i>	Olacaceae	Flowers white with tubular corolla ≤25 mm long; strong scent
<i>Psychotria sp.</i>	Olacaceae	Flowers white with corolla tube ≥ 8 mm; strong scent
<i>Crinum augustum</i> (the status of this species has not been settled; there is possible confusion with <i>C. amabile</i>)	Amariyllidaceae	Flowers white and deep pink with corolla tube ≤100 mm long; strong scent

Social breakdown as a population regulating process in invasive ant species.

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Abstract: Studies of invasive species have frequently recorded explosive population growth, often followed by decline. Causes of population stabilisation have rarely been explicitly identified; general mechanisms proposed have included intrinsic population dynamics and predators, parasitoids or pathogens attack. Some of the most harmful invasive species in terms of impacts on natural ecosystems are super-colony forming ants. Population processes within such colonies are of great importance to biodiversity conservation and the invasive species management. These super-colonies have only been reported from the invasive range and in their natural range the ants form small, dispersed colonies: low genetic variation in the introduced populations may facilitate super-colony development. The development of a 101 hectare crazy ant *Anoplolepis gracilipes* super-colony has been studied: by 2004 this had fragmented into 10 small isolated colonies. Here I show that colony breakdown was caused by intra-colonial social fragmentation, which will lead to the development of the low density, dispersed characteristics of natural colonies; this has notable implications for the control of invasive ant colonies and their impacts on biodiversity.

Keywords: *Anoplolepis*, Formicidae invasion, population structure, Seychelles

The crazy ant *Anoplolepis gracilipes* (SMITH, 1857) is regarded as one of the world's most invasive species, being listed as one of the 100 'worst alien species' (LOWE *et al.* 2001). It forms super-colonies where a large geographical area is occupied by a single colony with multiple queens or by numerous colonies that interact and operate as a single unit (TSUTSUI & SUAREZ 2003). These invasive super colonies have caused significant destruction of animal populations on tropical islands, most famously including significant reductions in the populations of land crabs on Christmas Island (GREEN *et al.*, 1999). In the Seychelles islands crazy ants have been present since 1962 (HAINES & HAINES 1978). By 2004 they were established on 11 islands (Mahé, Anonyme, St. Anne, Praslin, Curieuse, Cousin, Petite Soeur, Felicite, Marianne, La Digue and Bird island – Gerlach 2004 and unpublished data). Population expansion on Bird island caused high levels of mortality to the globally important nesting colony of sooty terns *Sterna fuscata* (FEARE 1999). Impacts on invertebrates and the pattern of colony expansion were studied in 2001-2 (GERLACH 2004). The island was found to be completely covered by a single super-colony of the ant by 2002, with population densities of 60m⁻² (GERLACH 2004). From this the total ant population could be estimated at some 60 million individuals (Fig. 1).

Materials and methods

In September 2004 the distribution and abundance of ants on Bird island was investigated in a repeat of earlier studies (GERLACH 2004). 100 1m² quadrats were placed haphazardly across the island. Leaf litter in these quadrats was collected and processed through Tulgren funnels to obtain accurate data on crazy ant abundance. These methods are comparable to those used in 2001 and 2002 (GERLACH 2004), providing a direct comparison to earlier data. In addition searches were made along all paths for the presence of crazy ant colonies.

Inter-colonial intections were studied using a standard behavioural assay as in previous studies of ant inter-colonial interactions (TSUTSUI & CASE 2001; GIRAUD ET AL. 2002; TSUTSUI & SUAREZ 2003). This paired two individual workers together in a neutral arena for 5 minutes. Interactions were scored as 1 = touching (without aggression, includes antennation), 2 = avoidance (one ant moving away from the other after physical contact), 3 = aggression (physical attack, includes lunging and biting) and 4 = fighting (prolonged biting and pulling, and use of chemical defences). 30 replicate trials were used pairing close nests (10m apart) and 30 pairing widely separated nests (200m apart). An additional study placed 10 worker ants (marked with a small dot of paint on the abdomen) in an arena with 10 workers from a different colony. After 15 minutes the ants were gathered into one or two groups, the composition of these groups was recorded. 10 replicates were used.

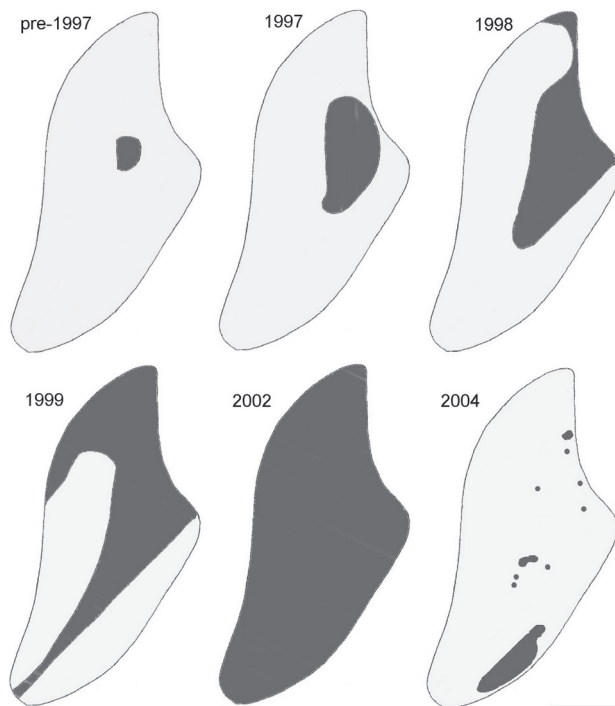


Fig. 1. Crazy ant distribution on Bird island 1997-2004 (dark areas). Scale bar 100m

Results

This study recorded crazy ants in only 20% of quadrats, compared to all quadrats in 2002 (69% in 2001 when the colony was still in the process of expansion). Ant densities in the quadrats where they were present were 0.6-50m⁻² (mean 18.8m⁻²), compared to 60m⁻² in 2002. 10 distinct colonies were located, covering a total of 0.0225 hectares (compared to 70ha in 2001 and 100ha in 2002). The estimated population is 26,000 individuals (a reduction of over 99% since 2002). No significant change occurred in the abundance or distribution of other ant species.

Inter-colonial interaction individual tests recorded only low levels of agonistic behaviour: individuals from adjacent nests showed behaviours 1 and 2 (1 at 7%, 2 at 93%); individuals from disparate nests showed behaviour 2 only (with one exception when aggressive behaviour 3 was observed) (Table 1). In the group tests ants from widely separated colonies had formed completely separate groups, those from adjacent colonies were largely separate, although there was a low level of overlap (5%) (Fig. 2).

Table 1. Behavioural interactions between ants from different colonies

Behavioural category	Number of observations	
	10m apart	200m apart
1	2	0
2	28	29
3	0	1
4	0	0

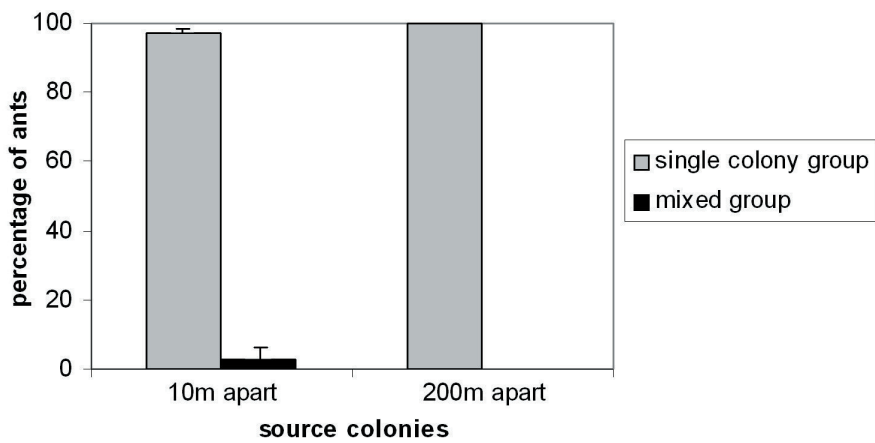


Fig. 2. Clustering behaviour of ants from different colonies, separating into either single colony or mixed groups

Discussion

The distribution pattern and the lack of interaction between workers from different colonies suggests that the super-colony that characterised the Bird island crazy ant population in 2002 has fragmented into at least 10 separate colonies. No significant aggression was observed between individuals or colonies but the low level agonistic behaviour and the avoidance of individuals from other colonies is probably sufficient to maintain colony isolation. This results in most of the island being free from resident crazy ants, foraging ants spread widely and foraging crazy ants probably cover most of the island but the impact of the ants is greatly reduced. This distribution resembles the very dispersed colony structures observed on the islands where the ants have been long established (Mahé, Praslin and La Digue) and the social fragmentation identified here may be an integral feature of population expansion in ants forming super-colonies. Other factors were not explicitly tested but there is no evidence of disease in the colonies, temperature and rainfall did not differ significantly over the study period, abundance and diversity of other ant species did not change and resource levels appeared to remain constant (as indicated by invertebrate abundance and vegetation cover).

Similar super-colonies have been reported in the Argentine ant *Linepithema humile* (GIRAUD *et al.* 2002; TSUTSUI & SUAREZ 2003; TSUTSUI *et al.* 2003). These form large colonies with low genetic diversity in introduced populations (TSUTSUI *et al.* 2003) compared to smaller (tens to hundreds of metres diameter) (TSUTSUI *et al.* 2000; TSUTSUI & CASE 2001), more isolated and more genetically diverse colonies in their native range which are aggressively defended from other conspecific ant colonies (SUAREZ *et al.* 1999; TSUTSUI *et al.* 2000; TSUTSUI & CASE 2001). A contrast between the low density, low impact native colonies and the high density, high impact invasive supercolonies has been noted (MARKIN 1970; RAO *et al.* 1991; HUMAN & GORDON 1996; HOLWAY *et al.* 1998; SUAREZ *et al.* 1998; HOLWAY 1999; GIRAUD *et al.* 2002; TSUTSUI *et al.* 2003). It is believed that new colonies are formed by budding from the super-colony, rather than by dispersal (TSUTSUI *et al.* 2003) and that the low genetic diversity of introduced populations facilitates the formation of supercolonies (TSUTSUI *et al.* 2003). The findings here suggest that the difference between the multicolonial natural populations and the unicolonial introduced populations may not be due to a fundamental difference between these populations, but to the length of time they have been established. The Bird island population suggests that over time the supercolony will fragment and form a number of smaller colonies. Continued isolation of these will reduce cooperation between the colonies and a reduction in the impact of the invasive ants. Consequently in a largely stable ecosystem the highly destructive unicolonial invasive ants populations may decline to less problematic levels over time. Although few ants are unicolonial, as all the invasive species possess this colony structure (PASSERA 1984; HOLWAY *et al.* 2002) this process of population regulation has major implications for ant invasions. These colonies may be highly damaging (GILLESPIE & REIMER 1993) as they spread but fragmentation may lead to the reduction of impacts, due not to extrinsic ecological factors but solely to social fragmentation. Given the phenomenally rapid spread of the highly invasive ant species these super-colonies may exceed their stable size relatively rapidly.

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Mortality, population changes and exceptional behaviour in a giant millipede

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Abstract: Four island populations of the Seychelles giant millipede *Sechelleptus seychellarum* were monitored between 1998 and 2005. In each population declines were detected between 1998-2002, population increases have occurred subsequently. This pattern of decline and increase corresponds to rainfall changes over the same period. The population declines were associated with high adult mortality. Behavioural experiments determined that adults would deliberately expose themselves to lethal temperatures in full sun and that such individuals were typically parasitised by larvae of the sarcophagid fly *Bercaea africana*. It appears that high levels of parasitism in dry years leads to high levels of mortality in giant millipedes and consequent population reduction. Rainfall increases reverse this pattern, resulting in fluctuating population levels. High altitude sites where rainfall is constantly high and there is little competition for shelter do not display such population fluctuations.

Key words: *Bercaea africana*, Diplopoda, population monitoring, Sarcophagidae, *Sechelleptus*, Seychelles

Introduction

Millipedes play a major role in the decomposition of organic material in many ecosystems through fragmentation of material (HANLON 1981), facilitating the action of microorganisms which carry out some 90% of chemical breakdown (ANDERSON & BIGNELL 1980). These processes occur in environments ranging from deserts (TAYLOR 1982) to tropical forests, with consumption of annual leaf fall estimated at up to 11% (BERTRAND *et al.* 1987). On small tropical islands millipedes may make up the majority of the detritivore biomass (pers. obs.) and may be the main organisms responsible for the initial processes of decomposition (LAWRENCE & SAMWAYS 2003). Despite their significant ecological role the ecology of tropical island species has rarely been studied.

Apparent 'suicidal' behaviour in the Seychelles giant millipede *Sechelleptus seychellarum* (DESJARDINS, 1834) was reported to the authors (observations by R. BRESSON *pers. comm.*). Whilst appearing unlikely this interpretation was in accordance with our own observations and accordingly merited further investigation. The Seychelles giant millipede is an abundant iteroparous detritivore found on most of the granitic islands of the Seychelles group (GOLOVATCH & KORSÓS 1992). It is predominantly nocturnal and during the day most individuals retreat into crevices or up trees (LAWRENCE 2000). There

do not appear to be any native predators of this species and although chemical defences (quinone exudation) are present they are used by only a small proportion of mature adults (pers. obs.). The principal causes of mortality appear to be natural senescence and exposure to the sun. Dead and dying adults are frequently observed in exposed areas but many apparently morbid individuals in these situations appear to recover when disturbed. Few juveniles are observed in such situations. These observations of mortality could arise from deaths in exposed areas being more visible to casual observers or to a real correlation between mortality and exposure. These observations were investigated through a study of mortality patterns in adult giant millipedes, using data from field studies on the islands of Silhouette, Aride, Cousine and Fregate.

Methods

The study comprised two components: population monitoring and investigation of mortality. Populations were monitored on four islands with different characteristics: a large island (1997 hectares, 774m altitude) with diverse habitats (Silhouette), an intermediate sized island (219ha, 125m) with limited diversity (Fregate) and two small *Pisonia grandis* woodland dominated islands (Cousine – 27ha, 65m; Aride – 68ha, 134m). Monitoring used different methods on each island. On Silhouette millipedes were counted on the ground and on trees visible along three 2m wide transects (listed in Table 1) passing through areas of forest and exposed rock. All transects were walked at 9:00-11:00am. These transects were walked 10 times each year, between 1999-2005. For each millipede located the following details were noted: length, sex (male, female, juvenile), health (active, morbid – alive but lying on its side, dead) and the canopy cover over a surrounding circle of 5m (estimated to the nearest 25%). On Fregate population density estimates were made in 1999 and 2002 in 10 5x5m quadrats in the main habitat types (*Pterocarpus* woodland, coastal woodland, mixed woodland, scrub, coconut plantation, agricultural and settlement. In each quadrat counts were made of the number of trees over 2m tall and millipedes on 20 haphazardly selected trees. Terrestrial millipedes were studied by recording the number under every moveable rock and log in each quadrat. On Cousine two surveys were carried out, in 1998 and 2003. These comprised 40 10x1m transects randomly paced in 10 study sites. Each transect was walked at night (20:00-22:30) and all millipedes observed were recorded. On Aride one 250m transect in *Pisonia grandis* woodland was used, from sea level to 100m a.s.l. This was studied at 10:00-13:00hrs twice a year from 2000-2005 (March/April and September). In each area studied habitat was characterised by recording estimates of percentage canopy cover, the depth of leaf litter and soil.

The mortality study investigated five factors:

1. Location of morbid millipedes (from the Silhouette transects as described above).
2. Use of burrows and resting places – in 20 2x2m quadrats on Silhouette island (5m inland from the Anse Mondon transect) all giant millipede burrows were excavated. These burrows are easily recognised, being tubular holes with an entrance diameter of 1-2cm. In each burrow all millipedes located were recorded and categorised as males, females or juveniles and live, morbid or dead.
3. Demographics and behaviour of millipedes - For each millipede its length, number

of segments, sex (if adult) and behaviour was recorded along with the exposure. Male giant millipedes are more slender than females (8-11mm wide compared to 14-16mm; pers. obs.). Behaviour was recorded as active (moving over the surface), resting (immobile but apparently healthy), hiding (partially hidden by a leaf or crevice), morbid (lying on side or back but still able to move their legs) or dead (no detectable movement even when disturbed). For dead and dying millipedes a note was made whether they were on the surface or partially hidden.

4. The process of death in morbid millipedes found in exposed sites - Morbid millipedes located along the transects were marked with a dot of white correction-fluid behind the head. They were then covered with a large leaf to eliminate exposure as an immediate mortality factor. On returning along the transect 2-4 hours later a search was made for each morbid millipede and its condition and behaviour noted. 30 morbid millipedes were collected and placed in vivaria containing earth and leaves. Observations of these captive individuals were made on an hourly basis until death occurred. Temperatures in the vivaria varied from 25.8-27.2°C in the leaf litter, 26.0-29.6°C on the surface in the shade and 28.3-69.7°C exposed to the sun.
5. Condition of morbid millipedes - The 30 millipedes observed above were dissected after death. The condition of the internal organs was examined to evaluate parasite load, locate any obvious cause of death and to determine the reproductive condition. These were compared to the organs of spirit preserved specimens collected as apparently healthy adults (collected as every 5th individual selected from millipedes showing rapid movement or disturbance until 30 were collected). A further 4 specimens from the Zoological Society of London's Invertebrate Conservation Unit were dissected, these had all apparently died of natural senescence and pathology examinations from this group had not located any disease or parasites. 6 dead millipedes from Aride and 4 from Cousine were also examined. 20 apparently healthy individuals were killed by freezing and dissected.

Results

Millipedes were abundant along the Silhouette island transects above 50m above sea level (Fig. 1). The highest densities were at mid-altitudes on the Belle Vue transect (200-250m a.s.l.) and the higher levels on the other transects (300-350m a.s.l. along Jardin Marron and 450-500m a.s.l. along Gratte Fesse). No significant population changes were detected over the study period. On Fregate and Aride millipede density decreased between 2000 and 2002 and on Cousine between 1998 and 2003 (Fig. 2).

92% of all 6762 millipedes located on Silhouette transects were adults (Fig. 3); 162 (2.6% of adults) were morbid and 69 (1.1%) dead. Dead and dying millipedes were found on all transects. These were exclusively found in relatively exposed areas (exposure of at least 75%). All except 9 dead individuals were fully adult and included both sexes (22 males, 38 females). Most were fully exposed on the surface (Fig. 4) while apparently healthy millipedes (n=6531) included 22% partially covered or hidden. All 71 dead millipedes on other islands were in fully exposed sites. 30 burrows were located, containing 42 millipedes (31% adult), all were alive.

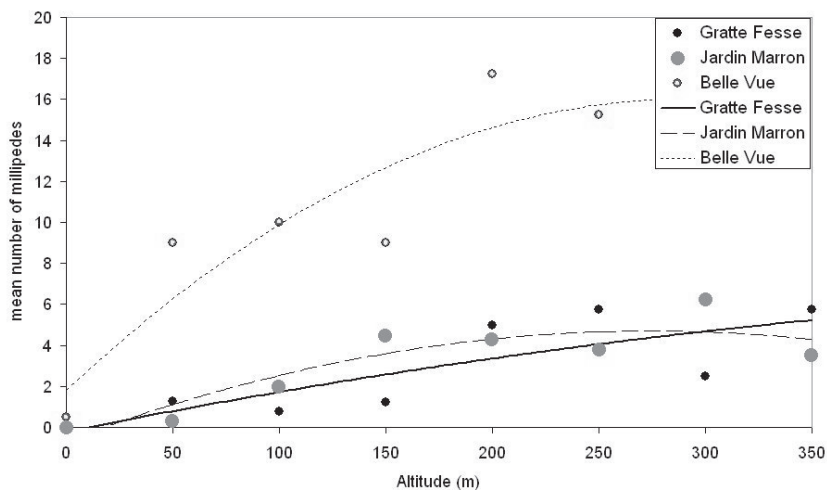


Fig. 1 Abundance of giant millipedes on Silhouette island (mean numbers in each transect section)

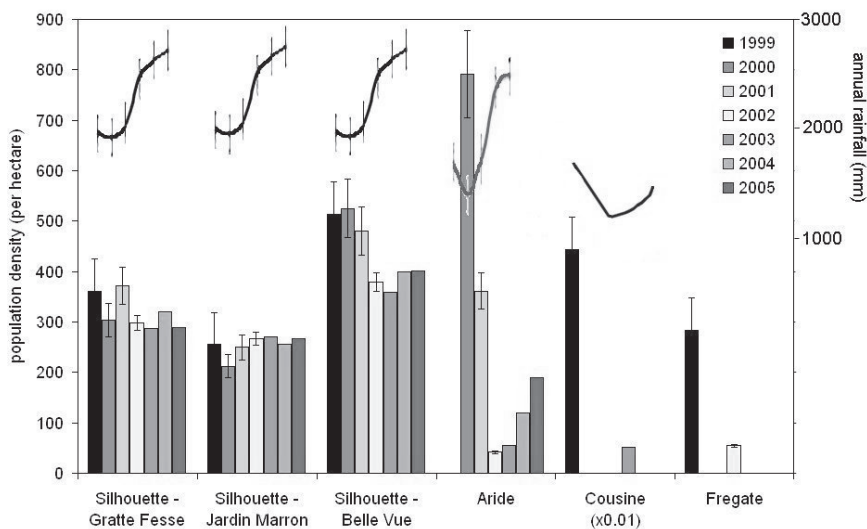


Fig. 2 Mean giant millipede population densities in the study sites (bars), rainfall shown for Silhouette, Aride and Cousine (lines)

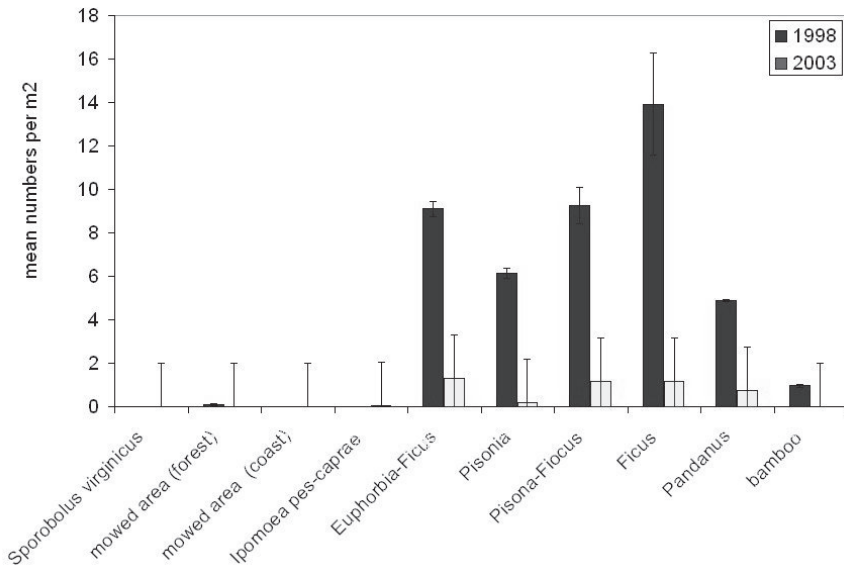


Fig. 3 Changes in millipede abundance on Cousine in 1998 and 2003

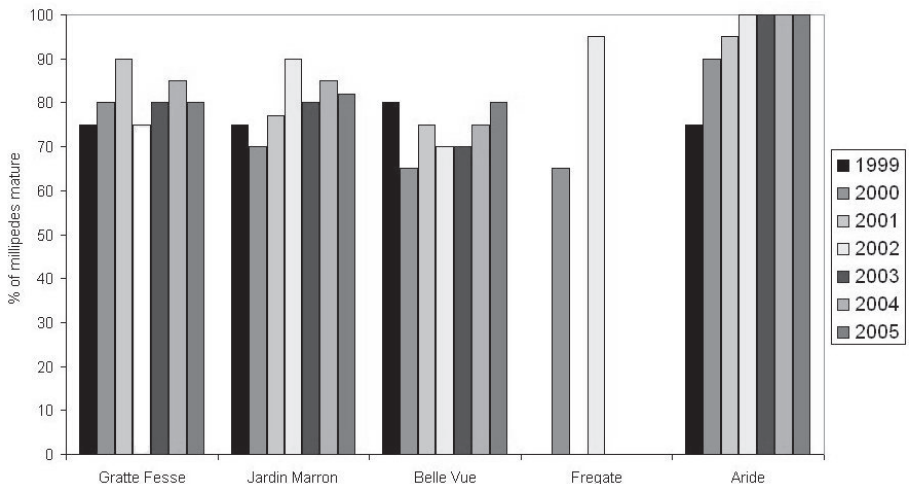


Fig. 4 Proportion of mature millipedes in each population

The 166 morbid millipedes located were found lying on their sides moving their legs slowly. On handling all attempted to move away, 36 were unable to do so effectively, the other 130 appeared to move normally. Covering resulted in two different responses; the 36 individuals unable to move effectively remained covered whilst all others were found to have moved 30-40cm away after 2 hours. These were found in 90

direct sunlight, lying on their sides. By this time the 36 immobile individuals and 71 of the others were dead. Covering 20 marked healthy millipedes in the field in the same manner resulted in 22 (75%) remaining covered, the other 8 (25%) could not be located within a 2m radius of the marking site.

In vivaria morbid millipedes remained on the surface. Movement continued throughout hours of darkness, within 1 hour of sunlight reaching the vivaria all 13 were lying on the surface in the half of the vivarium exposed to the sun, as originally found. They remained in this position, with irregular leg and antenna movements. There were no further movements, and all were dead 3-5 hours later. Dissection of 30 morbid millipedes revealed the presence of nematodes and larvae of the sarcophagid fly *Bercaea africana* (WIEDEMANN, 1824). Nematodes were abundant in most millipedes and infestation levels did not correlate with health (Table 2, $\chi^2=3.61$, $p=0.16$). All nematodes were located in the gut, none were in the body cavity or organs. Particular attention was paid to examining the brain and sense organs (eyes and antennae) but no differences could be found between morbid and healthy millipedes. *B. africana* final instar larvae were found in all body tissues of all dead millipedes and in 15 of the morbid millipedes. 3rd and 4th instar larvae were found in the remaining 15 morbid millipedes but none in the healthy individuals. Millipedes infested by *B. africana* larvae showed significant damage to all organs in the body cavity.

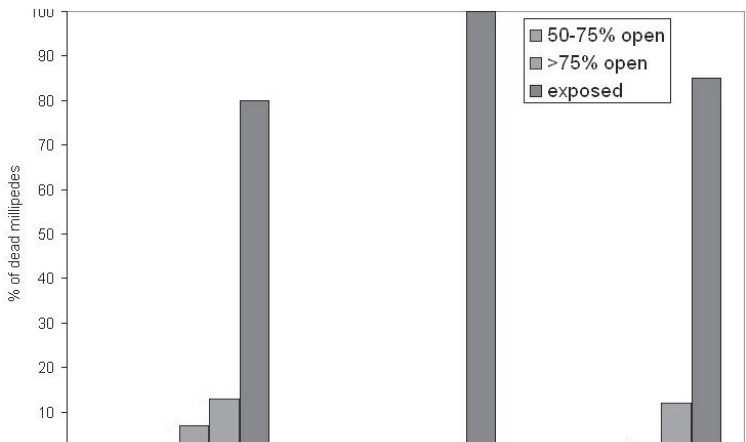


Fig. 5 The location of dead millipedes in areas of different exposure levels

Table 1 Location of transects and distribution of millipedes on Silhouette island

		La Passe - Gratte Fesse	La Passe - Jardin Marron	La Passe - Belle Vue
Length (km)		1.8	1.3	3.4
Altitude range		0-500m	0-450m	0-300m
Forest type		secondary, primary	secondary, primary	coconut plantation, secondary mid-altitude
Mean numbers	March	33.1	29.1	30.3
	September	29.9	22.4	26.1
	overall	32.3	24.1	28.2

Table 2. Parasite loads of millipedes collected on Silhouette island

	Sex	N	Millipedes with nematodes present	Mean number in infected individuals
Dead	Male	12	8	30±3.1
	Female	18	12	45±9.7
	Total	30	20	
Healthy	Male	10	3	33±6.0
	Female	10	5	40±8.1
	Total	20	8	
Morbid	Male	15	8	34±7.1
	Female	15	10	35±10.4
	Total	30	18	

Discussion

Of the areas examined on Silhouette island the Belle Vue transect appears to have the highest millipede densities and the greatest mortality levels (Table 1, Fig. 4). Millipedes can frequently be found entering holes around the bases of rocks and under logs whilst on the other transects millipedes are usually only seen when fully active, feeding or mating. On the Gratte Fesse and Jardin Marron transects millipedes have rarely been observed entering holes but are occasionally seen climbing trees or moving into the spaces between boulders. The presence of such boulder cavities is the major topographical difference between the transects with an absence of such spaces on the earth slopes of the Belle Vue transect. Similarly, of the other islands studied those with the deepest soils tended to have the lowest relative mortality levels.

The causes of mortality and population decline could include climatic stress or parasitism. No evidence of predation or changes in food availability was detected. During the study period, temperature and humidity have remained fairly stable but rainfall has increased on all islands. The pattern of increasing rainfall since 2001 is followed by increases in the lowland millipede populations with an approximately one year lag (Fig. 4). The cause of the apparently rainfall-driven pattern of millipede populations may result either from a direct rainfall influence on survival or reproduction or from an indirect impact on an additional factor. Mortality factors resulting in millipede death on the surface of the ground appear to be most significant in adults and were directly associated with the presence of *Bercaea africana* larvae. *B. africana* infected millipedes show a strong thermophilic tendency. All apparently morbid individuals consistently positioned themselves in exposed positions, resulting in their death. This could be interpreted as an accidental result of age related sensory impairment, parasite-mediated self-immolation, a deliberate suicidal act or deliberate exposure to heat the body as a behavioural ‘fever’ in a parasite removal strategy. The first two explanations are unlikely to account for the observations due to the lack of any detectable sensory damage or any differences in parasite load. Deliberate suicidal behaviour is improbable in a non-social invertebrate. The behavioural ‘fever’ hypothesis could operate, but the repetition of this action until mortality results and the lack of any survivors would make evolution of such a maladaptive strategy in this situation highly problematic. However, such a maladaptive strategy may occur as long as parasite infestations levels remain low. If parasite levels are exceptional they could result in host population declines.

Bercaea africana is known to be a parasite of several animal species, including snails, grasshoppers and mammals (VERVES 2003). It is a cosmopolitan species and

has been recorded in Seychelles since 1908 (BEZZI 1923; VERVES 2003). It is probably an indigenous species with the interaction with the giant millipedes being a natural occurrence. The population decline observed on Frégate, Cousine and Aride may be a result of excessively high *B. africana* infestations on these islands. *B. africana* is associated with open habitats (pers. obs.) which characterise the Belle Vue path on Silhouette and all habitats on Frégate, Aride and Cousine. Increases in *B. africana* as a result of rainfall and possibly additional unknown factors (climatic variation or changes in food abundance, such as dead birds or rats) may lead to high parasitism levels and population declines.

This species shows notable population changes in response to climatic variation, this appears to be a cyclical or variable process, with no evidence of a long-term sustained decline. Based on IUCN Red List criteria (IUCN 2001) the species can be categorised as Vulnerable (criteria B2ac(iv)) with a total area of occupancy of 34.6km², present at 9 locations and with extreme fluctuations in area number of mature individuals. Individuals of one population (Frégate island) are well established in captivity (FERGUSON & PEARCE-KELLY 2005) and some populations (Aride, Cousin and Cousine) are within legally protected areas. Population monitoring should continue as this species may be considered an indicator of climate change (GERLACH *et al.* 2005).

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The Lepidoptera of Cousine Island, Seychelles

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Introduction

This reports provides an overview of all Macro-lepidoptera collected on Cousine Island (4°20'S; 55°40'E) between 5 June 2002 and 30 April 2003. The topography, climate and vegetation of Cousine have been described by BOURQUIN (1996; 1997). Besides short publications on the butterflies of Cousine (BOURQUIN, *ET AL.* 2000; LAWRENCE 2000; LAWRENCE 2004a), and some brief unpublished notes on the Sphingidae moths (Lawrence 2003), very little has been written on the Lepidoptera of Cousine. As much new information has since come to light, a more comprehensive report is presented. A total of 18 species are discussed in terms of their distributions within and outside Seychelles, as well as known foodplant selection in relation to Cousine's floral diversity. Lepidoptera taxonomy follows that of LEGRAND (1965), while floral taxonomy follows Robertson (1989).

Systematic list

1) *Diaphana indica* (SAUNDERS, 1851) (Pylalidae: Pyraustinae)

A widespread species in Seychelles, being recorded from the Seychelles islands of Mahé, Praslin, Fregate, Bird, Coetivy, Silhouette and Aldabra (LEGRAND 1965). On Cousine this species was collected on 07 October 2002.

Its distribution outside Seychelles includes most of the Afrotropical region, parts of the Oriental and Australian regions, where larvae have been recorded on Cucurbitaceae plants (PINHEY 1975). Interestingly, the specimen was collected roosting under the leaves of *Cucurbita moschata* (DUCH. ex LAM). On Mahé larvae were found on *Achyranthes aspera* L. (Amaranthaceae) (LIONNET 1984), which is commonly found on Cousine (BOURQUIN 1996), but is being removed as it is an invasive weed.

2) *Syngamia abruptalis* (WALKER, 1859) (Pylalidae: Pyraustinae)

This Palaetropical species was collected on Cousine on 8 October 2002. the Seychelles records include Mahé, Silhouette (Legrand 1965) and North Island (GERLACH *et al.* 2001).

Larvae have been recorded on various Labiatae, (*Ocimum basilicum* L. and *Plectranthus* sp.), *Elephantopus* sp. (Compositae) and *Gossypium* sp. (Malvaceae) (GERLACH *pers. comm.*). *Gossypium hirsutum* L. has been recorded on Cousine (Bourquin 1996). However, as it is considered invasive, attempts have been made to eradicate it from Cousine.

3) *Uresiphita limbalis* (DENIS & SCHIFFERMULLER, 1775) (Pylalidae: Pyraustinae)

Another Palaetropical species collected on Cousine on 13 April 2003. Also recorded

from Mahé (LEGRAND 1965) and Silhouette (GERLACH *pers. comm.*).

Known foodplants include *Sophora* sp. (Papilionaceae) (Gerlach *pers. comm.*), and *Cedrela* sp. (Meliaceae) (KROON 1999). No records exist for the occurrence of any Papilionaceae or Meliaceae on Cousine, although both *Sophora tomentosa* L. and *Cedrela odorata* L. occur on other Seychelles islands (ROBERTSON 1989).

4) *Thalassodes antithetica* HERBULOT, 1964 (Geometridae: Geometrinae)

A Seychelles endemic species recorded from Mahé and Silhouette (Legrand 1965). On Cousine, a specimen was collected on the 16 February 2003.

5) *Perigea pauperata* (WALKER, 1858) (Noctuidae: Amphipyridae)

A widespread species that was collected on Cousine on 25 September 2002 and 15 November 2002. In both cases, specimens were attracted to lights in the early evening. In Seychelles, this species has been recorded from Mahé and Fregate (GERLACH *pers. comm.*). Its distribution outside Seychelles includes the Afrotropical region and its islands.

Known larval foodplants include *Caropsis* sp. (Apiaceae) (KROON 1999). However, as ROBERTSON (1989) does not list any Apiaceae from Seychelles, it must use other plant families for larval foodplants. Other species of *Perigea* are known to use the Asteraceae (particularly *Bidens pilosa* L.) which is widespread in Seychelles (ROBERTSON 1989).

6) *Hypena masuralis* GUENÉE, 1854 (Noctuidae: Hypeninae)

A Palaetropical species that is widespread in Seychelles being recorded from Cetyv, Frégate, Aride, Praslin, Mahé, Silhouette and Cachée (LEGRAND 1965; ARIDE ISLAND RESEARCH GROUP 1999; GERLACH *pers. comm.*). On Cousine the species was collected on the 28 April 2003.

Known foodplants include both *Commelina diffusa* BURM. f. (Comellinaceae) and *Desmodium* sp. (Papilionaceae) (GERLACH *pers. comm.*). BOURQUIN (1996) lists *Commelina benghalensis* L. as occurring on Cousine.

7) *Achaea catella* (GUENÉE, 1852) (Noctuidae: Catocalinae)

Not recorded during this study, but listed as being collected on Cousine by BOURQUIN (1997). Also recorded from Aride (ARIDE ISLAND RESEARCH GROUP 1999), Mahé (LEGRAND 1965) and Silhouette (GERLACH 1998). This species is widely distributed throughout the Afrotropical region, where its larvae have been recorded on various Leguminosae (*Bauhinia* sp. and *Tamarindus* sp.) (PINHEY 1975). Although *Bauhinia* sp. and *Tamarindus* sp. do not occur on Cousine, six other Leguminosae species are known to grow on Cousine (Bourquin 1996).

8) *Parallelia angularis* (BOISDUVAL, 1833) (Noctuidae: Catocalinae)

Previously recorded from the Seychelles islands of Mahé (Legrand 1965) and Silhouette (GERLACH *pers. comm.*). On Cousine this species was collected on 1 October 2002 and again on 13 March 2003. Outside Seychelles this species has been recorded throughout

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most of the Afrotropical region including its islands (PINHEY 1975).

Larval foodplants include *Phyllanthus* sp. (Euphorbiaceae) (GERLACH *pers. comms*). Four species of *Phyllanthus* are known to occur on Cousine: *P. amaurus* SCHUM. & THONN, *P. nummularifolius* POIR., *P. casticum* WILLEM, and *P. acidus* (L.) Skeels (BOURQUIN 1996).

9) *Remigia conveniens* WALKER, 1858 (Noctuidae: Catocalinae)

Recorded from the Seychelles islands of Mahé, Poivre, Praslin, Felicite and Silhouette (LEGRAND 1965). On Cousine, a dead specimen was found on the coastal flat on 8 October 2002. A widespread species found in Central America, the Afrotropical and Indo-Malaysian regions (PINHEY 1975). It is known to feed on the Proteaceae which has only been recorded on Mahé as an ornamental (GERLACH *pers. comm.*).

10) *Herse convolvuli* (L., 1758) (Sphingidae: Acherontiinae)

Recorded from the Seychelles islands of Mahé, Farquhar, Silhouette (LEGRAND 1965) and Aride (ARIDE ISLAND RESEARCH GROUP 1999). On Cousine, the first specimen was collected in November 1996. A further specimen was collected on the 21 March 1998. During this study, *H. convolvuli* were regularly encountered being attracted to lights during November. specimens were collected from the coastal flat on the NE side of Cousine.

A late instar larva was seen being eaten by a Seychelles magpie robin (*Copsychus sechellarum* Newton) on the coastal flat in December 2002, indicating that this species was breeding on the island. Adults were also observed feeding from flowers of *Hymenocallis littoralis* (JACQ.) SALISB. (Amaryllidaceae) in the early evening. Outside Seychelles this species is widely distributed, including most of the African continent, Europe, Asia and Australia. *H. convolvuli* has been recorded on various Convolvulaceae (PINHEY 1975) of which *Ipomoea pescaprae* (L.) R.Br., *I. macrantha* ROEM. & SCHULTES and *I. venosa* (DESR.) ROEM. & SCHULTES have been recorded on Cousine. On Mahé, *H. convolvuli* larvae have been recorded on *Tabebuia* sp. (Bignoniaceae) (LIONNET 1984). As *H. convolvuli* is also a well known migrant (PINHEY 1975), it is quite possible that this species has only recently become established on Cousine.

11) *Acherontia atropos* (L., 1758) (Sphingidae: Acherontiinae)

Recorded from the islands of Mahé and Silhouette (LEGRAND 1965). Several late instar larvae were found feeding on the leaves of *Cordia subcordata* LAM. (Boraginaceae) on 1 April 2003. Larvae were bred through to adult to confirm identification. On Mahé, *A. atropos* larvae have been recorded on *Momordica charantia* L. (Cucurbitaceae), *Tabebuia* sp. (Bignoniaceae) and *Clerodendron* sp. (Verbenaceae) (LIONNET 1984).

This conspicuous species appears to also only have recently have become established on Cousine, as there have been no prior records for this species on the island. Records also exist for this species breeding on *Datura* sp. (Solanaceae) (PINHEY 1975). *D. metel* L. has been recorded on Cousine (BOURQUIN 1996), but as it is an invasive weed, it is slowly being eradicated from Cousine, and at the time of the study

only occurs as isolated plants.

12) *Borbo borbonica morella* (JOANNIS, 1893) (Hesperiidae: Hesperinae)

Dealt with previously by BOURQUIN, *et al.* (2000). However, no individuals were seen during this study. As the Afrotropical nominate subspecies is migratory (Larsen 1996), it is quite possible that previous specimens collected on Cousine were migrants from the larger islands, and that this Seychelles endemic subspecies is not permanently resident on Cousine. Another possibility is that in certain years it occurs in low numbers and is overlooked. Other Seychelles records include Mahé, Praslin, Aldabra (BERGER 1962; LEGRAND 1965), Aride (ARIDE ISLAND RESEARCH GROUP 1999) and Cousin (HILL, *et al.* 2003).

BOURQUIN, *et al.* (2000) records it as being scarce on Cousine, and is seen from October to April, usually near the *Pisonia/Ficus* forest edge. Larval foodplants of the nominate subspecies include various grasses (Henning, *et al.* 1997) of which numerous species have been recorded on Cousine (BOURQUIN 1996).

13) *Borbo gemella* (MABILLE, 1884) (Hesperiidae: Hesperinae)

The ecology and biology of this species on Cousine has been dealt with by LAWRENCE (2004a). This species has only recently been recorded as occurring on Cousine. However, as both *B. borbonica morella* and *B. gemella* are very similar in appearance, confusion between the two could easily have occurred, especially with identifying individuals on the wing.

This species is widespread in Seychelles, with it being recorded from the following islands: Mahé, Silhouette, Praslin, Aride, Coetivy, Alphonse, Platte and Aldabra (BERGER 1962; LEGRAND 1965; ARIDE ISLAND RESEARCH GROUP 1999). Outside Seychelles, it occurs throughout most of Africa and SW Arabia (LARSEN 1996).

On Cousine, the flight period is throughout the year, with it being most commonly encountered between November and January. Like *B. borbonica morella*, it also favors the *Pisonia/Ficus* forest edge biotope. Larval foodplants include various Poaceae (KROON 1999). On Cousine, LAWRENCE (2004a) recorded eggs being laid on the upper surfaces of young *Stenotaphrum dimidiatum* (L.) BRONGN. swards.

14) *Lampides boeticus* (L., 1767) (Lycaenidae: Polyommatainae)

Previously recorded from Cousine by BOURQUIN, *et al.* (2000), with five individuals seen between the 14th and 15th March 1998. During this study, two further individuals were seen on the coastal flat, one on 5 December 2002 and the other on 8 February 2003. Short visits to Mahé (Beau Vallon) on 3 June 2002, and to Praslin (Plaine Hollandasie) on 29 August 2002 indicated that this species was quite abundant on the larger islands during the SE monsoon period.

Seychelles distributions listed by Legrand (1965) include Mahé, Silhouette and Cosmoledo. Also recorded from Aride by the ARIDE ISLAND RESEARCH GROUP (1999). Outside Seychelles, this species is widespread, occurring from western Europe and Africa, through the Indo-Malayan area to Australia, the islands of the west Pacific and as far as Hawaii (Common & WATERHOUSE 1981; GAY, *et al.* 1992).

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Larval foodplants include various legumes (PRINGLE, *et al.* 1994). Legumes are not common on Cousine, but are well represented (BOURQUIN 1996). As *L. boeticus* is strongly migratory (ACKERY, *et al.* 1995), and its occurrence on Cousine is sporadic, this species may not at present be breeding on Cousine.

15) *Zizeeria knysna* (TRIMEN, 1862) (Lycaenidae: Polyommatainae)

Another species briefly dealt with by BOURQUIN, *et al.* (2000). A commonly encountered species found over the entire island, especially the coastal flat, throughout all months of the year. Recorded from the Seychelles islands of Mahé, Saint Anne, Silhouette, Praslin, Farquhar, Desroches, Aigle, Bird, Denis, Cousin, Aride and North (LEGRAND 1965; LAWRENCE 2004b). Outside Seychelles its range extends from Mediterranean Europe to western and southern Africa (HIGGINS & HARGREAVES 1991).

Larvae are known to feed on a large variety of foodplants, including *Amaranthus* sp. (Amaranthaceae) (KROON 1999) and *Euphorbia* sp. (Euphorbiaceae) (PRINGLE, *et al.* 1994). On Cousine females were observed ovipositing on *Amaranthus dubius* MART. ex THELL. during the SE monsoon period. Also, three species of *Euphorbia* (i.e. *E. hirta* L., *E. prostrata* AIT. and *E. pyrifolia* LAM.) grow on Cousine (BOURQUIN 1996).

16) *Vanessa cardui* (L., 1758) (Nymphalidae: Nymphalinae)

First recorded from Cousine by Bourquin (2000). Occasionally encountered on Cousine's coastal flat areas. Previous records are from April and March. However, an individual was seen during January 1998. During this study only two individuals were seen, one on the 7 December 2002 and the other on the 23 April 2003.

Within Seychelles this species has been recorded from the islands of Mahé, Sainte-Anne, Coetivy, Assumption, Desroches (LEGRAND 1965) and Aride (ARIDE ISLAND RESEARCH GROUP 1999). Recently (April 2005) this species has also been recorded from Bird Island (M. NORAH *pers. comm.*). Outside Seychelles this species is cosmopolitan, though absent from most of South America (LARSEN 1996).

Larval foodplants include members of the Boraginaceae, Compositae and Malvaceae (VAN SON 1979; PRINGLE *et al.* 1994), of which representatives of all are found on Cousine (BOURQUIN 1996). As this species is a very well known migrant (ACKERY *et al.* 1995), it may explain its sporadic occurrence on Cousine and other islands such as Bird. As yet, there is no direct evidence of this species breeding on Cousine. However, the specimen collected on Cousine during April 2003, was a freshly emerged individual with little signs of damage to its wings, possibly indicating that it was not a migrant.

17) *Hypolimnys misippus* (L., 1764) (Nymphalidae: Nymphalinae)

The ecology of this species on Cousine was dealt with by Lawrence (2000) and BOURQUIN *et al.* (2000). This species is widely distributed in Seychelles, being recorded from the islands of Mahé, Saint Anne, Silhouette, North, Praslin, Aride, Aldabra, Cosmoledo, Coetivy, Desroches and Cousin (LEGRAND 1965; LIONNET 1984; GERLACH *et al.* 1997; ARIDE ISLAND RESEARCH GROUP 1999).

Outside Seychelles, this species is widely distributed, occurring throughout the Orient, Afrotropics, U.S.A. (Florida), West Indies, French Guiana and NE Brazil

(ACKERY *et al.* 1995).

During this study, this species was recorded during late November, early December 2003, and again during March, April 2003. When on the wing, adults were commonly encountered on the coastal flat area of Cousine.

H. misippus females are well known mimics of *Danaus chrysippus* (L.). The following female forms were recorded on Cousine by LAWRENCE (2000): f. *misippus* (L.); f. *alcippoides* BUTLER; f. *dorippoides* AURIVILLIUS; f. *inaria* CRAMER. One specimen collected by LAWRENCE (2000) was an intermediate form between f. *immima* BERNARDI and f. *aclippoides*.

Larval foodplants include the Acanthaceae and Portulacaceae (NOLET 1984; PRINGLE *et al.* 1994; KROON 1999). On Cousine both families are represented by *Asystasia* sp. and *Portulaca oleracea* L. respectively (BOURQUIN 1996).

18) *Melanitis leda helena* (Westwood) (Nymphalidae: Satyrinae)

Recorded from the Seychelles islands of Mahé, Silhouette, Cosmoledo, Aldabra, Coetivy, Desroches (LEGRAND 1965), North and Aride (ARIDE ISLAND RESEARCH GROUP 1999). Outside Seychelles, this subspecies occurs throughout most of the Afrotropical region, including its islands, and Arabia (ACKERY *et al.* 1995).

A total of four individuals were seen during the study. The first individual was seen on 30 November 2002. A further two specimens were seen on the 28 and 29 December 2002. The final specimen was seen on 9 January 2003. All individuals were seen in the under-story of the *Pisonia* and *Ficus* forest areas.

Larval foodplants include various grasses (KROON 1999) of which numerous species have been recorded on Cousine (BOURQUIN 1996). Interestingly, all specimens seen were in fresh condition with little or no wing damage indicating that they were not migrants from the larger surrounding islands.

Discussion

Only 18 species were recorded on Cousine during this study (plus a further 6 other records – Appendix I) indicating that Lepidoptera are not abundant on this island. However, this list is certainly not complete. A single unidentified geometrid moth was collected during February 2003. Unfortunately the specimen was damaged before being identified. Also, no attempt was made to collect the Micro-lepidoptera.

Based on the above systematic list, approximately 89% of Cousine's known lepidoptera are widespread species commonly found throughout the Afrotropical region and in some cases further. Only two of the above taxa are endemic to Seychelles, one being an endemic species (i.e. *T. antithetica*), and the other an endemic subspecies (i.e. *B. borbonica morella*). Unfortunately, *B. borbonica morella* was not collected during this study, indicating that this species may not always be present on Cousine, or occurs in low numbers in certain years.

Another feature of Cousine lepidopterous fauna is that several of the species are well known migrants. This is clearly supported by many of the migrant species only being recorded once or sporadically. This is not unexpected, as migrant species would be the most likely ones to colonize isolated ecosystems, such as islands. Moreover,

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most of the species recorded during this study have known larval foodplants growing on Cousine, so the potential for these sporadically encountered species becoming established is favorably. However, island ecosystems are extremely dynamic and species change over would be rapid and common place.

Acknowledgments

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Appendix I. Other Lepidoptera records from Cousine

The following species were recorded by J. GERLACH in 2001:

- Orthoctha rhodothicta* (MEYRICK, 1911) (Tineidae) Endemic
- Metachanda thaleropis* MEYRICK, 1911 (Metachandidae) Endemic
- Epicroesa* sp. (Heliodinidae) Endemic
- Marasmia poeyalis* (BOISDUVAL, 1833) (Pyrilidae) Palaeotropical
- Marasmia trebiusalis* (WALKER, 1859) (Pyrilidae) Palaeotropical
- Hypenodes croceipicta aegrota* BERIO, 1962 (Noctuidae) Endemic subspecies

Invertebrates associated with the Seychelles sheath-tailed bat *Coleura seychellensis*

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The Seychelles sheath-tailed bat *Coleura seychellensis* PETERS, 1868 is a Critically Endangered (IUCN 2004) emballonurid bat restricted to the granitic islands of Seychelles. Three roost sites are known on Mahé and Silhouette. Of these the largest roost is on Silhouette, occupied by 32 individuals (Gerlach 2004). The Silhouette roost has been studied in detail since 2003 (GERLACH 2004). Observations of the roosts and the bats within it have identified a number of invertebrate species associated with the bats. Two occupied and two unoccupied cave within the roost system have different characteristics and different invertebrate faunas. Roost A is comparatively large and open, this is used regularly, usually in the early morning and late afternoon. Roost B is more enclosed and is the main permanent roost, this is also the only identified breeding site for the species. Roost C is a small abandoned roost that may have been used only occasionally. Roost D is intermediate in characteristics between roosts A and B. It is

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currently abandoned but was from the guano deposits appears to have been a significant roost in the past. The invertebrates observed in the roosts are listed below:

Roost A

Cardisoma carnifex (HERBST, 1794) (Crustacea: Decapoda) – small numbers found outside the roost, entering at night and feeding on guano

Heteropoda venatoria (LINNAEUS, 1767) (Chelicerata: Arachnida) – small numbers present in the roost at night

Isometrus maculatus GEER, 1778 (Chelicerata: Scorpiones) – one shed skin

Seychellsia nitidula BOLIVAR, 1912 (Insecta: Orthoptera) – common on the rocks at the roost entrances

Roost B

Coenobita brevimanus DANA, 1852 (Crustacea: Decapoda) – small numbers (1-3) feeding on guano at night

Heteropoda venatoria (Chelicerata: Arachnida) – common on rocks at night

Streblidae (Insecta: Diptera) – one encased bat fly larva observed feeding on a juvenile bat (Fig. 1)

Monomorium sp. (Insecta: Hymenoptera) – foraging in guano at night

Crypsithyroides concolorella (WALKER, 1863) (Insecta: Lepidoptera) – highly abundant in guano, a species associated with bird and bat guano

Roost C

Crypsithyroides concolorella (Insecta: Lepidoptera) – old larval cases found in the small guano deposit

Roost D

Crypsithyroides concolorella (Insecta: Lepidoptera) – dead but apparently recent larval cases found in the significant guano deposit.

These observations indicate that there is only a small invertebrate fauna associated with bat caves in Seychelles, the presence of crabs feeding on guano is notable. *Cardisoma carnifex* eliminate all guano from the floor of roost A but are unable to enter roost B, the smaller hermit crabs appear to be less efficient guano feeders and a deep guano deposit has built up in this roost. Highly characteristic of most roosts is the presence of larval cases of the moth *Crypsithyroides concolorella*, these are not present in roost A which has a relatively open aspect compared to the other roosts. The unidentified bat fly larva is probably an obligate associate of the Seychelles sheath-tailed bat, as there are no other potential hosts within the granitic islands it probably represents an undescribed endemic species, which will share Critically Endangered status with its host.

Acknowledgements

I am grateful to Steve GOODMAN for comments on the bat fly and to Gaden ROBINSON for identification of the moth *Crypsithyroides concolorella*.

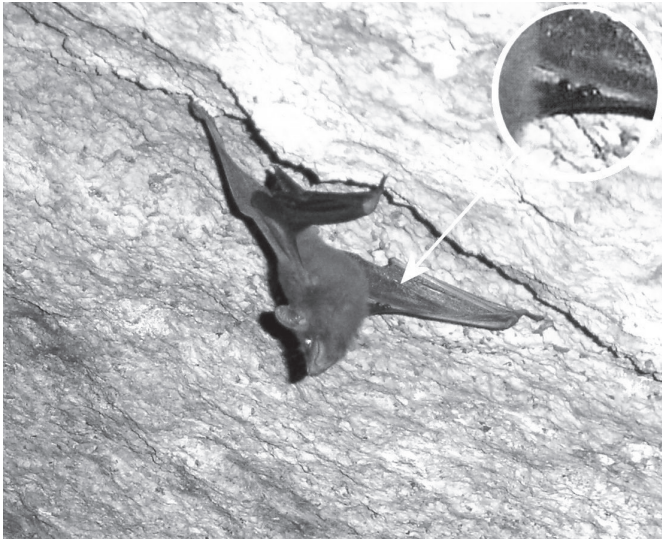


Fig. 1 Bat flies on the fore-arm of a Seychelles sheath-tailed bat

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First record of the genus *Kapala* Cameron (Hymenoptera: Chalcidoidea, Eucharitidae) from Seychelles

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Members of the small family Eucharitidae containing 413 species worldwide (HERATY 2002) are known as parasitoids of ants. Until now 13 species (and one subspecies) have been recorded from Madagascar (HERATY 2002), but only one species, *Stilbula lissoma* MASI, 1917, is known from the Seychelles (Silhouette). Apparently the family Eucharitidae is absent from the other islands of the Malagasy Subregion.

The specimen has been identified by John M. HERATY during his stay in Vienna 1999 and deposited in the Hymenoptera Collection, Naturhistorisches Museum Wien.

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Kapala ivorensis RISBEC, 1954

Material: Praslin: Anse Boudin 1 sp. 7-10.6.1999 leg. Madl.

This is the only Ethiopian member of the genus *Kapala*, CAMERON, 1884, which is distributed mainly in the Neotropical Region. *Kapala ivorensis* is known from Sierra Leone, Ivory Coast, Nigeria, Cameroon, Kenya, Uganda, Zaire and Madagascar. The host is probably the ponerine ant *Odontomachus troglodytes* SANTSCHI, 1914.

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Review of the Pentatomidae of Seychelles (Hemiptera, Heteroptera)

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Introduction

Recently the Pentatomidae of the Seychelles islands (inner, granitic islands of Seychelles) have been reviewed by ROCHE (1977). Up to date nine species have been recorded, but the distribution and the biology of the species are still imperfectly known. The material has been collected by several scientists during projects not focussed on Hemiptera. It contains six species already known from the Seychelles. Three species (*Nezara viridula* (LINNÉ, 1758), *Bathycoelia fleuria* ROCHE, 1977 and *Parachinavia creolea* ROCHE, 1977) are recorded as new to the fauna of Silhouette, *Bathycoelia praelongirostris* BERGROTH, 1893, is new to the fauna of Saint Anne and *Acrosternum heegeri* FIEBER, 1861 is new to the fauna of Bird island.

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Acronyms of collections

NHMW: Naturhistorisches Museum Wien, Hymenoptera-Sammlung

NPTS: Nature Protection Trust of Seychelles, Silhouette

Catalogue and material from the Seychelles islands (= inner Seychelles)*Amirantea gardineri* DISTANT, 1909

Amirantea gardineri n. sp.: DISTANT 1909: 31 (descr.), pl. 4 (fig. 1)

Amirantea gardineri DISTANT. 1909: DISTANT 1913: 144 (biol., distr.)

Amirantea gardineri DISTANT. 1909: ROCHE 1977: 560 (key), 561 (descr.)

Amirantea gardineri DISTANT. 1909: SCOTT 1933: 337 (biol.), 347

Amirantea gardineri DISTANT. 1909: GERLACH, ET. AL. 1997: 20 (cat.)

Distribution: Inner Seychelles: Mahé, Silhouette.

Endemic. Only recorded from Mahé and Silhouette in 1905 and 1908.

Acrosternum heegeri FIEBER, 1861

Nezara heegeri (FIEBER, 1861): DISTANT 1913: 144 (distr.)

Chinavia emmeresi (SCHOUTEDEN, 1905): ORIAN 1965: 28 (tax.)

Acrosternum heegeri FIEBER, 1861: ROCHE 1977: 560 (key), 561 (tax., distr.)

Nezara heegeri (FIEBER, 1861): GERLACH, MATYOT & SAARISTO 1997: 20 (cat.)

Acrosternum heegeri FIEBER, 1861: ARIDE ISLAND RES. GROUP 1999: 50 (distr.)

Acrosternum heegeri FIEBER, 1861: GERLACH 2003: 17 (distr.)

Distribution: Inner Seychelles: Mahé, Silhouette, Aride, Bird – Aldabra Group: Aldabra, Assumption

Material examined:

Silhouette: La Passe, 1m, light trap 1 female 30.7.-1.8.2000 leg. J. GERLACH (NPTS); at light 1 female 7-13.5.2002 leg. MADL (NHMW).

Bird: 1 male, 21-26.3.2003 leg. J. LAWRENCE (NPTS).

Aldabra. – Esprit, 4.5.2004 leg. U. SAMEDI (NPTS).

Known from the southern Palearctic and Ethiopian Region. Reported to be ‘one of the commonest Pentatomidae on MAHÉ.’ (ROCHE 1977). A new record for Bird island

Bathyoelia cascadea ROCHE, 1977

Bathyoelia cascadea n. sp.: ROCHE 1977: 560 (key), 566 (descr.), 567 (figs. 11-14)

Distribution: Inner Seychelles: Mahé, Silhouette, Praslin.

Material examined:

Mahé: Beau Vallon, 20.9.2004 leg. J. GERLACH (NPTS).

Silhouette: La Passe, at light, 3 males 17.7.1998, 1-6.4.2004 leg. J. Gerlach (NPTS). La Passe, at light, 2 males, 4 females 16-22.5.2003 leg. MADL (NHMW).

Endemic to the Inner Seychelles. Previously recorded from Mahé (Cascade, Mt. Fleuri, Anse la Mouche, Bel Ombre), Praslin (Fond l’Anse), Silhouette (Mare aux Cochons) in 1970 and 1972-3 (ROCHE 1977).

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***Bathypoelia fleuria* ROCHE, 1977**

Bathypoelia fleuria n. sp.: ROCHE 1977: 560 (key), 567 (figs. 15-18), 569 (descr.)

Bathypoelia fleuria ROCHE, 1977: GERLACH 2003: 17

Distribution: Inner Seychelles: Mahé, Silhouette, Praslin.

Material examined:

Mahé: Petite Police Bay 1 male 4. 5. 2002 leg. MADL (NHMW).

Silhouette: La Passe, at light, 5-14.6.2004 leg. J. GERLACH (NPTS). 1 male 7-13.5.2002; at light, 10 males, 12 females 16-22.5.2002 leg. MADL (NHMW).

Endemic to the Inner Seychelles. New to the fauna of Silhouette; previously recorded from Mahé (Mt. Fleuri, Bel Ombre, Anse la Mouche), Praslin (Grand' Anse, Anse Boudin) in 1971-2 (ROCHE 1977).

***Bathypoelia praelongirostris* BERGROTH, 1893**

Bathypoelia praelongirostris n. sp.: BERGROTH 1893: 198 (distr.), 200 (descr.)

Bathypoelia praelongirostris BERGROTH, 1893: DISTANT 1913: 144 (distr.)

Bathypoelia praelongirostris BERGROTH, 1893: ROCHE 1977: 560 (key), 566 (tax.)

Bathypoelia praelongirostris BERGROTH, 1893: GERLACH, ET. AL. 1997: 20 (cat.)

Bathypoelia praelongirostris BERGROTH, 1893: CADBURY 2001: 65 (distr.)

Bathypoelia praelongirostris BERGROTH, 1893: GERLACH 2003: 17 (distr.)

Distribution: Inner Seychelles: Mahé, Saint Anne, Silhouette, Aride – Coetivy.

Material examined:

Saint Anne: 30 m, at light, 10.12.2001 leg. J. GERLACH (NPTS).

Silhouette: La Passe, at light, 1 male 16-22.5.2003 leg. Madl (NHMW). La Passe, at light 6.4.2004, 5-6.6.2004 leg. J. GERLACH (NPTS)

Aride: 2 m, on *Peponium vogelii*, 1 sp. 1.7.2000 leg. L. CADBURY (NPTS).

Endemic to the Inner Seychelles. New to the fauna of Saint Anne; previously recorded from Mahé in 1892, Mahé, Silhouette and Coetivy in 1905 and 1908-9 (Roche 1977).

***Chinavia spicata* (DISTANT, 1913)**

Nezara acuta DALLAS 1851: DISTANT 1909: 38 (distr.)

Nezara spicata n. sp.: DISTANT 1913: 143 (descr.)

Nezara acuta DALLAS 1851: BERGROTH 1893: 198 (distr.)

Chinavia spicata (DISTANT, 1913): ROCHE 1977: 559 (key), 563 (figs. 1, 4, 6, 8), 564 (tax., distr.)

Nezara spicata DISTANT, 1913: GERLACH, MATYOT & SAARISTO 1997: 20 (cat.)

Chinavia spicata (DISTANT, 1913): GERLACH, WILLI & GERLACH 2001: 37 (distr.)

Chinavia spicata (DISTANT, 1913): GERLACH 2003: 17 (distr.)

Distribution: Inner Seychelles: Mahé, Silhouette, North.

Material examined:

Silhouette: Belle Vue, 200 m, on *Clidemia hirta* 1 male, 1 female 17.7.2000 leg. J. GERLACH & J. WILLI (NPTS).

North: 2 m, 1 male 1 female 29.7.2000 leg. J. GERLACH, J. WILLI & R. GERLACH (NPTS).

Endemic to the inner Seychelles islands, ROCHE (1977) reported the species to be

common on Mahé.

***Nezara viridula* (LINNÉ, 1758)**

Nezara viridula (LINNÉ, 1758): BERGROTH 1893: 198 (distr.)

Nezara viridula (LINNÉ, 1758): DISTANT 1913: 143 (distr.)

Nezara viridula var. *smaragdula* (FABRICIUS, 1775): FREEMAN 1940: 357 (descr., distr.)

Nezara viridula (LINNÉ, 1758): ROCHE 1977: 560 (key), 562 (distr.)

Distribution: Inner Seychelles: Mahé, Silhouette, Bird, Denis.

Material examined:

Silhouette: La Passe, sea level, at light. 5-6.6.2004. leg. J. GERLACH (NPTS).

A cosmopolitan species. In the Malagasy Subregion recorded from Madagascar, Réunion, Mauritius and Cargados Islands. Recorded from Mahé in 1892, 1905, 1908-9 and reported to be 'far from common' by ROCHE (1977).

***Parachinavia creolea* ROCHE, 1977**

Parachinavia creolea n. sp.: Roche 1977: 560 (key), 565 (typ. gen., descr., figs. 9, 10)

Parachinavia creolea Roche, 1977: Gerlach 2003: 17

Distribution: Inner Seychelles: Mahé, Silhouette.

Material examined:

Silhouette: La Passe 10.12.2004 leg. J. GERLACH (NPTS). Pointe Zeng Zeng 1 female 12.5.2002 leg. MADL (NHMW).

Endemic to the Inner Seychelles. New to the fauna of Silhouette, previously only reported from Mt. Fleuri on Mahé in 1972 (ROCHE 1977).

***Phricodus hystrix* (GERMAR, 1839)**

Phricodus hystrix (GERMAR, 1839): ROCHE 1977: 560 (key), 570 (tax., distr.)

Distribution: Inner Seychelles: Mahé.

Known from the Ethiopian and Oriental Region. In the Malagasy subregion recorded from Madagascar and Mauritius. Reported to be 'not uncommon on Mahé' by ROCHE (1977).

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Table 1. Distribution of Pentatomidae in the Republic of Seychelles. P = present

Species	Inner islands		Silhouette	North	Praslin	Aride	Bird	Denis
	Mahé	St. Anne						
<i>Acrosternum heegeri</i>	P		P			P	P	
<i>Amirantea gardineri</i>	P		P					
<i>Bathycoelia cascadea</i>	P		P		P			
<i>Bathycoelia fleuria</i>	P		P		P			
<i>Bathycoelia praelongirostris</i>	P	P	P			P		
<i>Chinavia spicata</i>	P		P	P				
<i>Nezara viridula</i>	P		P				P	P
<i>Parachinavia creolea</i>	P		P					
<i>Phricodus hystrix</i>	P							

Species	Coetivy	Aldabra Group		Cosmoledo
		Aldabra	Assumption	
<i>Acrosternum heegeri</i>		P	P	
<i>Bathycoelia praelongirostris</i>	P			
<i>Carbula marginella</i>		P		P
<i>Eusarcocoris imperator</i>		P	P	
<i>Menida transversa</i>		P		
<i>Stenozygum aldabranum</i>		P		
<i>Stenozygum insularum</i>				P